

The Effects of Aerosols on California and South Coast Climate

Mark Z. Jacobson

Dept. of Civil & Environmental Engineering

Stanford University

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Scientific Question

What are the global climate effects of particulate soot (black carbon and organic matter) and of all anthropogenic greenhouse gases plus particles?

What are the effects in California and the South Coast Air Basin of all anthropogenic particles and their gas precursors on

rainfall

pollution content of rainwater

cloudiness

near-surface air temperatures

vertical temperature profiles

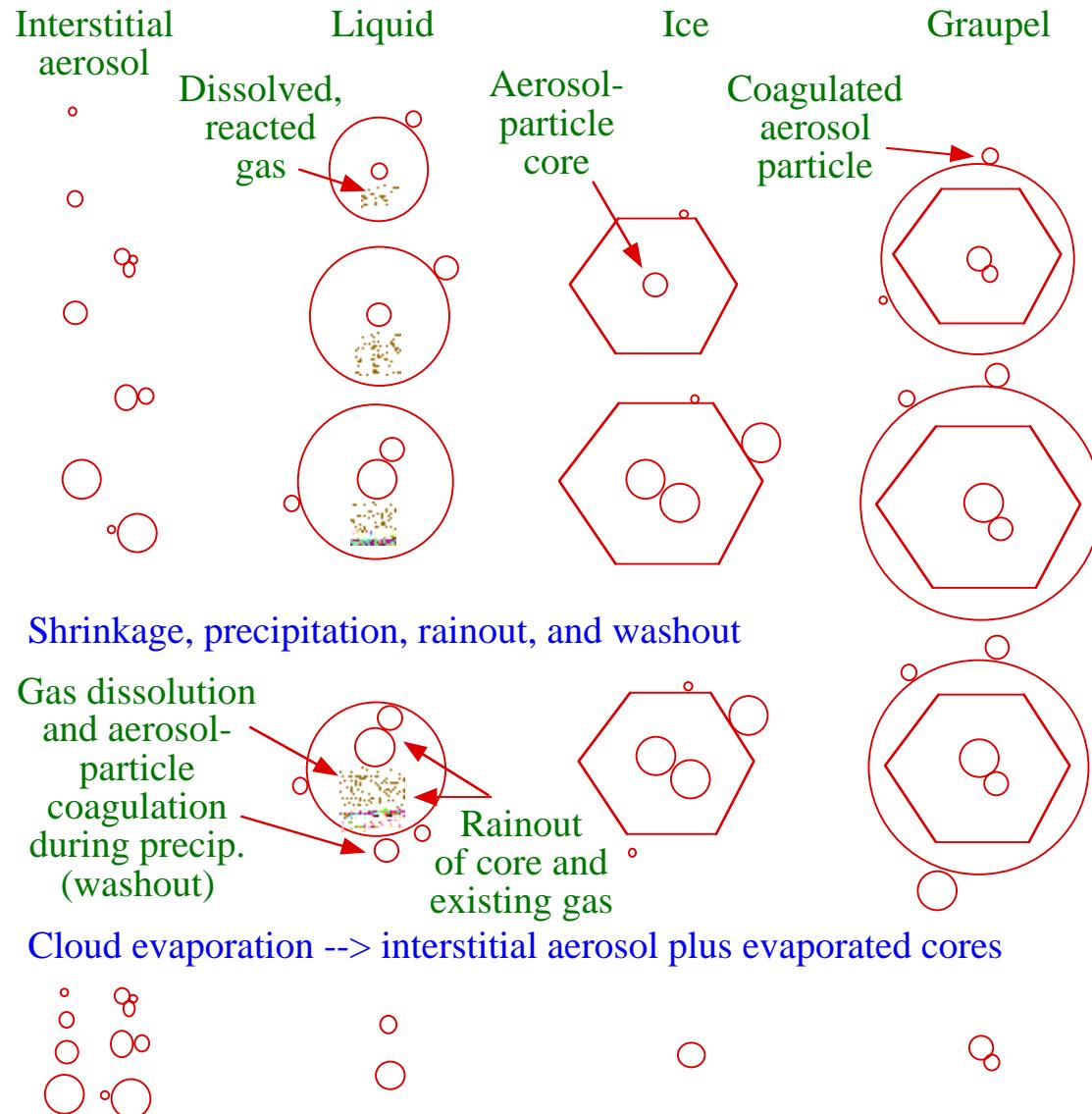
relative humidity

ultraviolet/total solar/thermal-infrared radiation

GATOR-GCMOM

- Gas processes
 - Emission
 - Photchemistry
 - Gas-to-particle conversion
 - Cloud removal
- Aerosol processes
 - Emission
 - Nucleation/condensation
 - Aerosol, cloud coagulation
 - Dissolution/chemistry/crystallization
 - Dry deposition/sedimentation
 - Rainout/washout
- Cloud processes
 - Activation on aerosol
 - Condens./evap./deposition/sublim.
 - Hom./het./contact/evap. freezing
 - Cloud, aerosol coagulation
 - Precipitation/lightning
 - Dissolution/chemistry
- Radiative transfer
 - UV/visible/near-IR/thermal-IR
 - Scattering/absorption
 - Gas
 - Aerosol
 - Hydrometeor
 - Predicted snow, ice, water albedos
- Meteorological processes
 - Velocity
 - Pressure
 - Temperature
 - Turbulence
 - Geopotential
 - Water vapor
 - Density
- Surface processes
 - Temperatures and water content of
 - Soil
 - Water
 - Snow
 - Sea ice
 - Vegetation
 - Roads
 - Roofs
 - 2-D ocean module
 - 3-D ocean diffusion, chemistry
 - Ocean-atmosphere exchange

Aerosol-Cloud Interactions



Estimated Global Direct Forcing (W/m²)

Anthropogenic Greenhouse Gases (IPCC, 2001)

- Carbon Dioxide +1.46
- Methane +0.48
- Nitrous oxide +0.15

Fossil-fuel+Biomass-Burning BC (*Nature* 409, 695, 2001; *GRL* 27, 217, 2000)

- Internally mixed as a core +0.62
- Multiple distributions (int.+ext. mix) +0.55 (Best estimate)
- Externally mixed +0.31

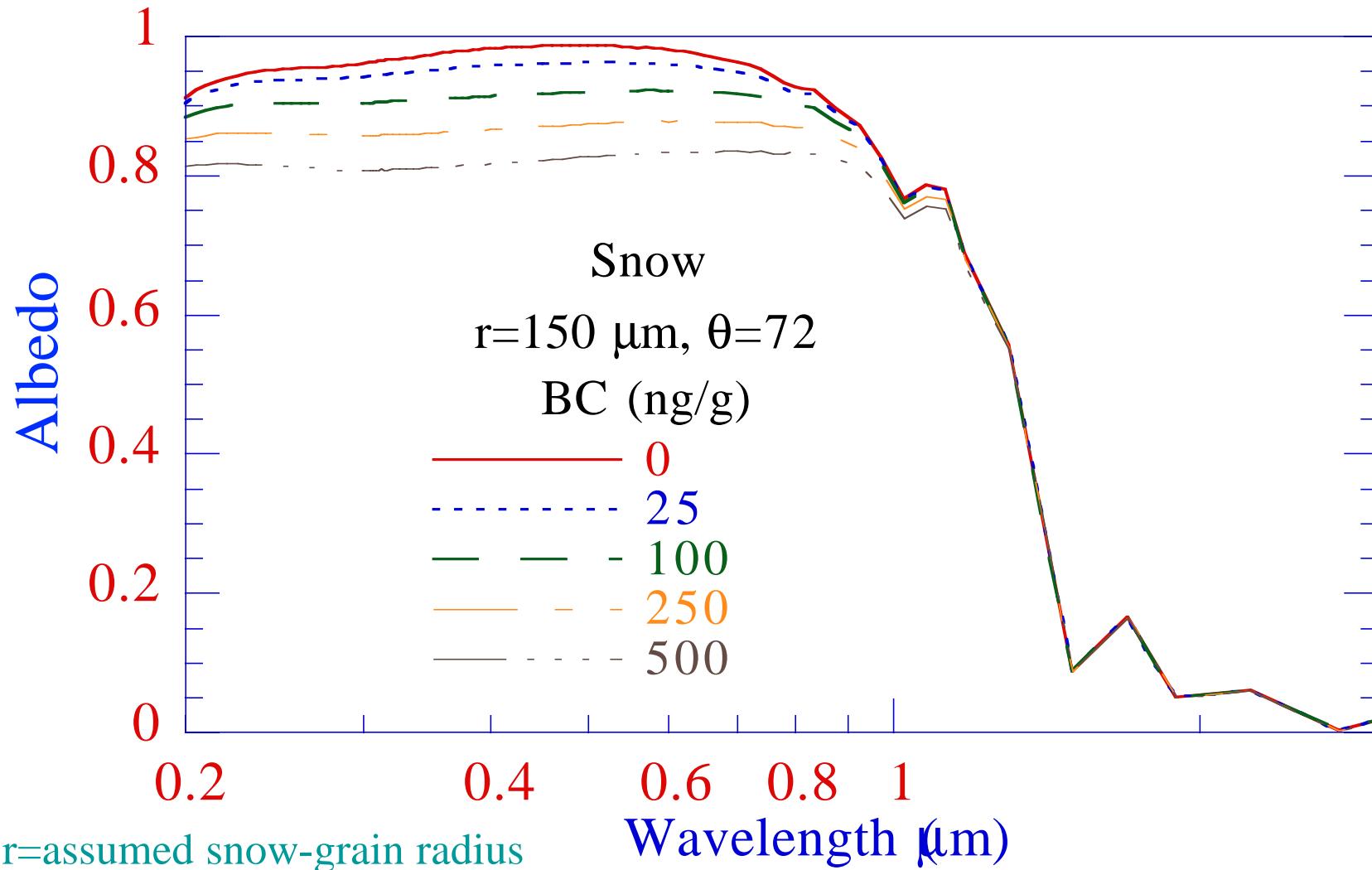
Ff+bb BC (Chung and Seinfeld *JGR* 107, D19, 2002)

- Well-mixed internally +0.8
- Externally mixed +0.51

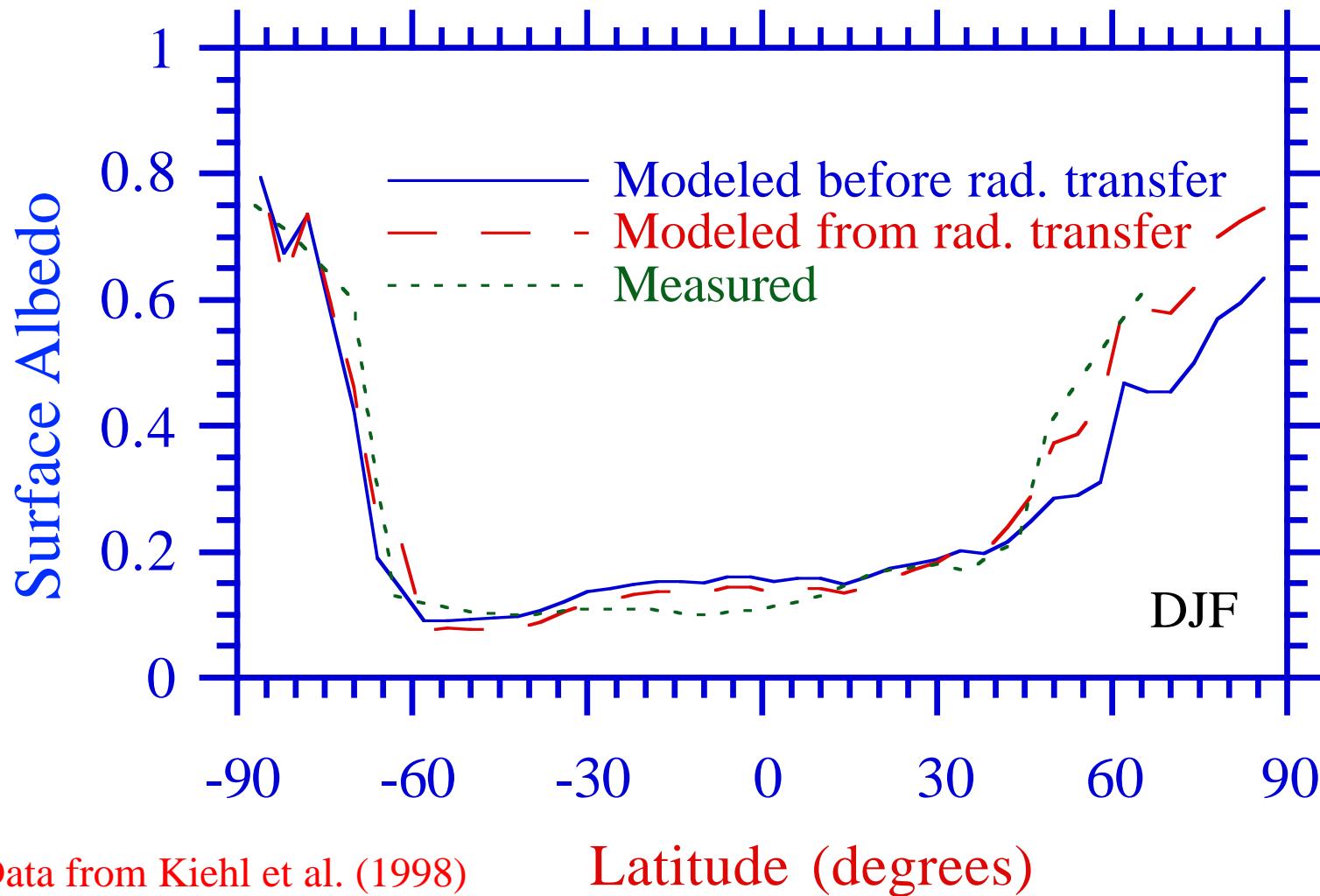
Comparison of ff BC Climate Responses

1. Jacobson (JGR 107, D19, 2002). One aerosol size distribution; multiple components, size-resolved cloud formation on aerosols and treatments of first and part of second indirect effects, climatological albedo, emission of Cooke et al. (1999), 2-D ocean, many feedbacks.
 - Fossil fuel BC+OM: +0.3 K (5-y average)
Range (+0.15 to +0.5)
2. *Ibid.* (JGR 2004, in press). Same as (1) but treated complete second indirect effect, calculated snow/ice albedo, early Bond et al. (2004) emission.
 - Fossil fuel + biofuel BC+OM: +0.27 K (10-y avg. snow contrib. +0.06 K)
3. *Ibid.* Recent results. Same as (2) but with most recent Bond et al (2004) emission, two size distributions, 10 layers of energy diffusion to deep ocean.
 - Fossil fuel + biofuel BC+OM: +0.29 K (6-y avg.)

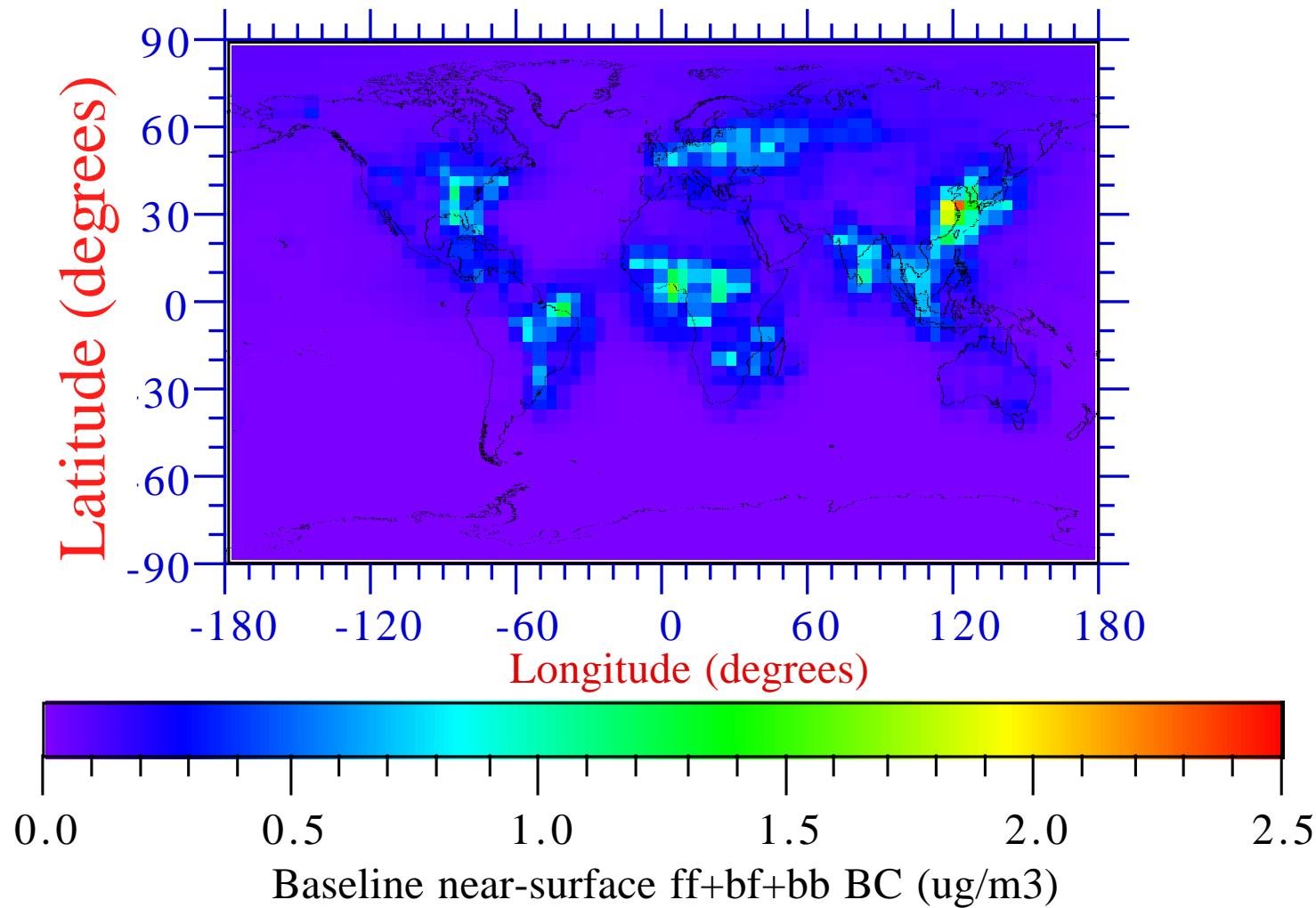
Modeled (from Radiative Transfer) Albedo Of Snow With Internally+Externally- Mixed BC Inclusions



Ten-Year-Avg. Modeled v. Measured DJF Albedo

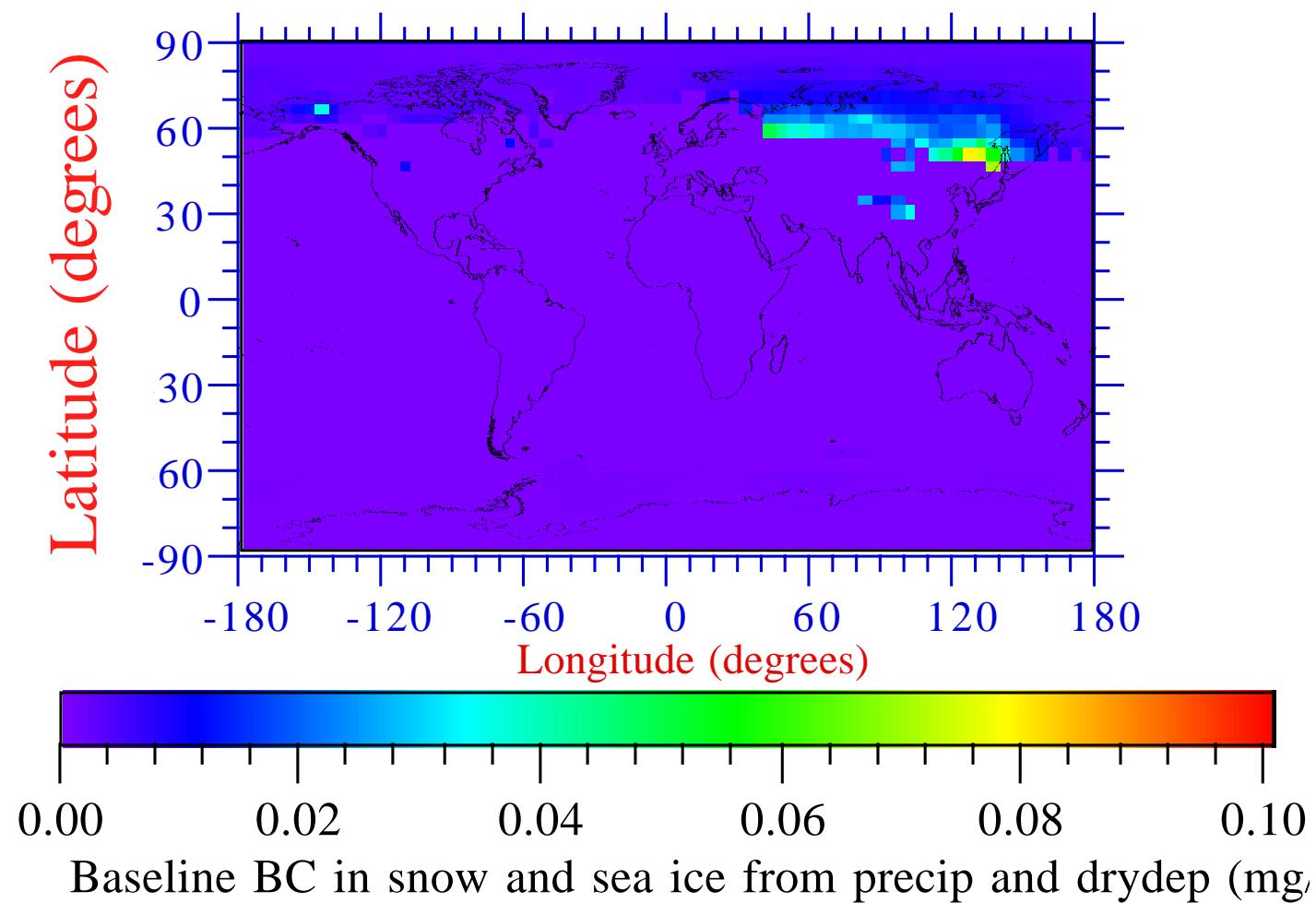


Ten-Year-Avg. Modeled BC From Fossil Fuels, Biofuels, and Biomass

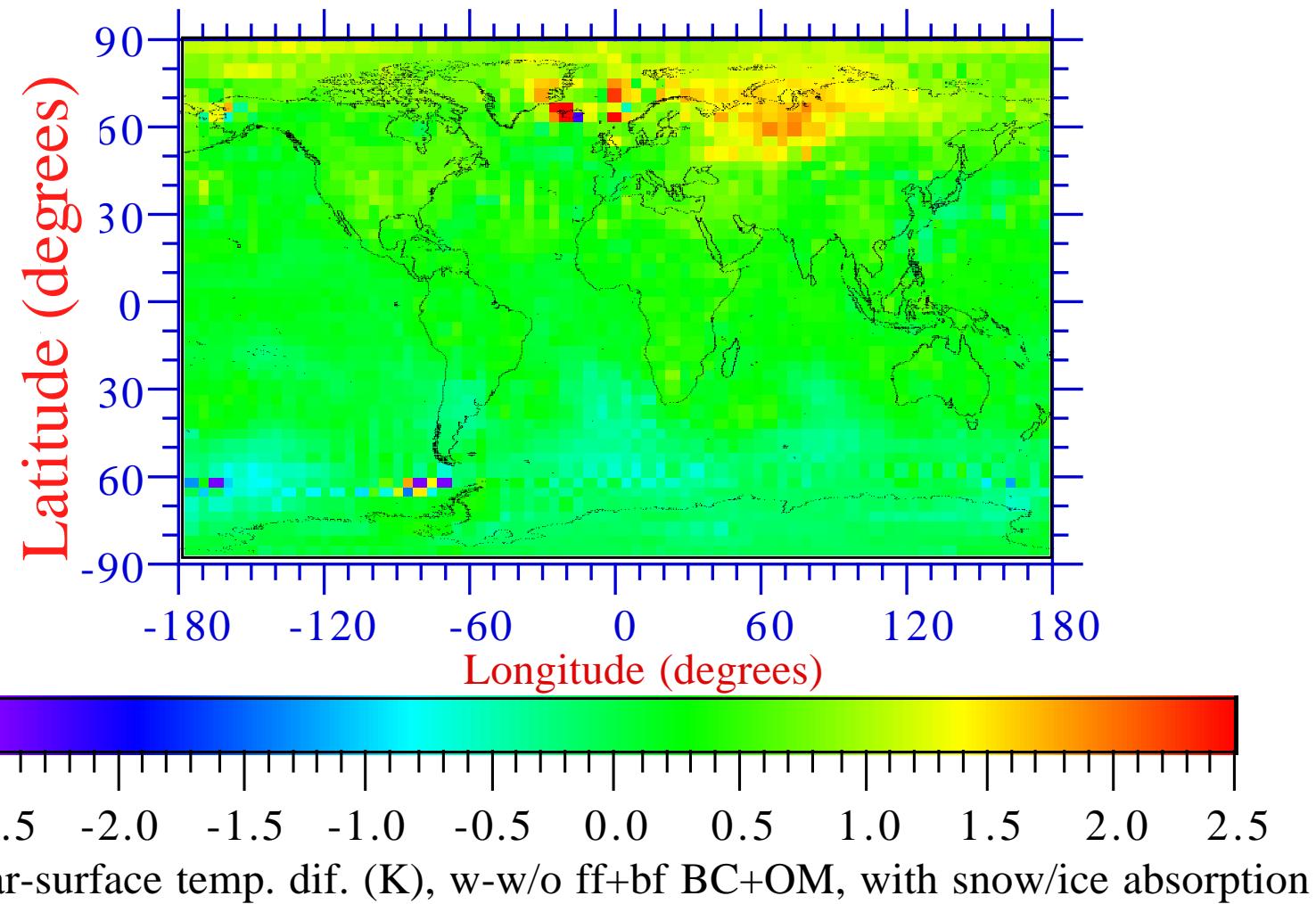


Emissions from early version of Bond, Streets et al. (2003):
3.9 Tg-ff+bf-BC-C, 6 Tg-ff+bf-OC-C, 3.1 Tg-bb-BC-C, 25.6 Tg-bb-OC-C

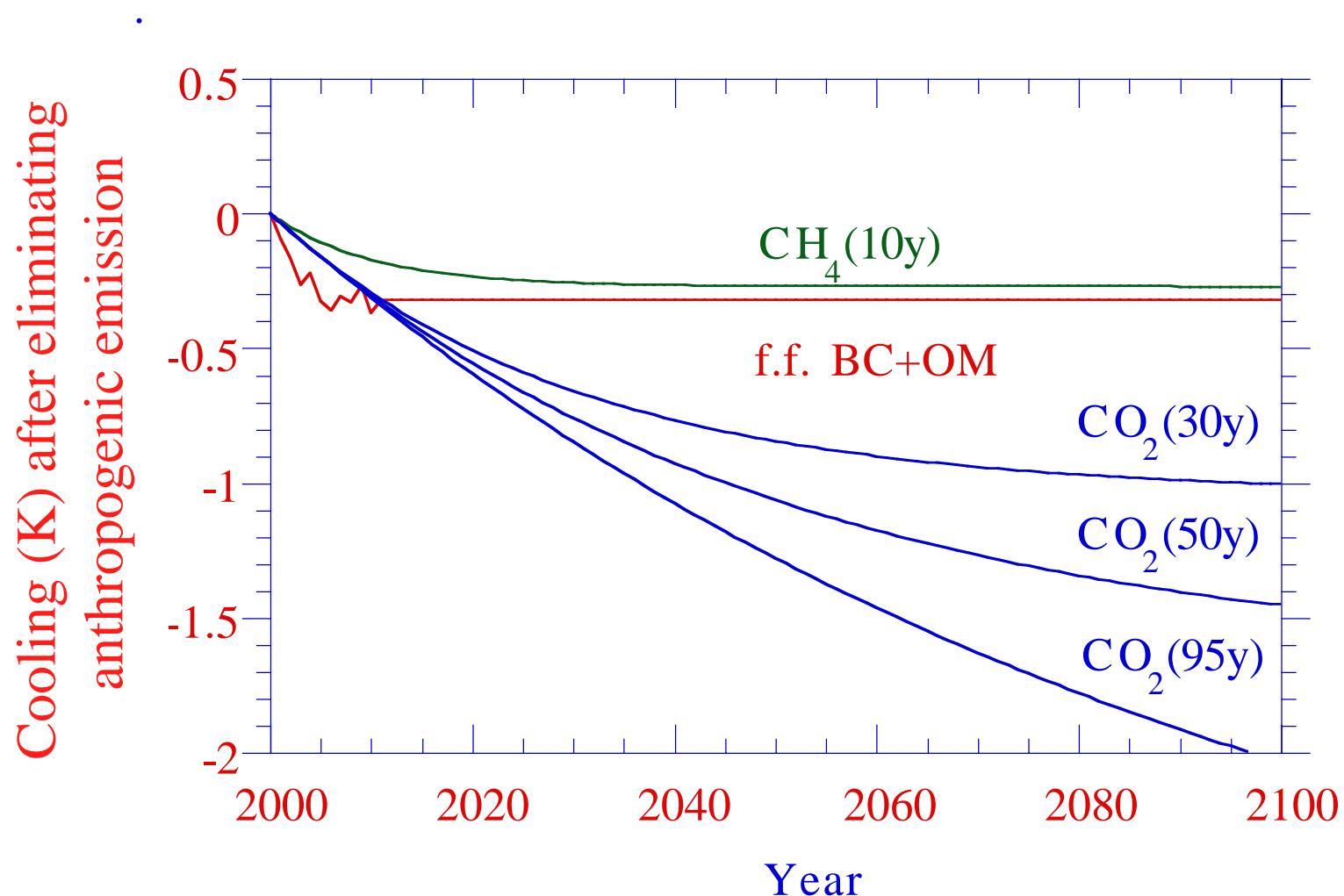
Modeled BC in Snow and Sea Ice



Ten-year Avg. Temperature Difference w-w/o ff+bf BC

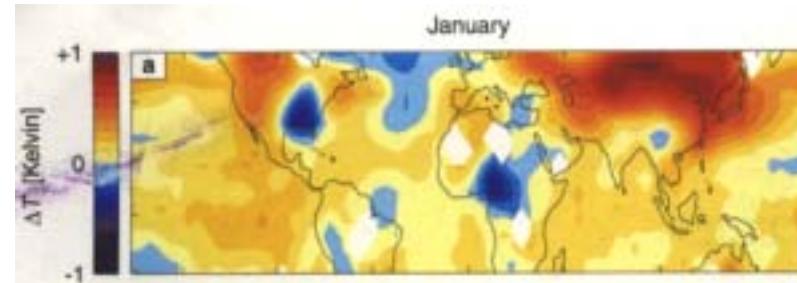


Temperature Changes Due to Eliminating Emission of Anthropogenic CO₂, CH₄, and f.f. BC+OM

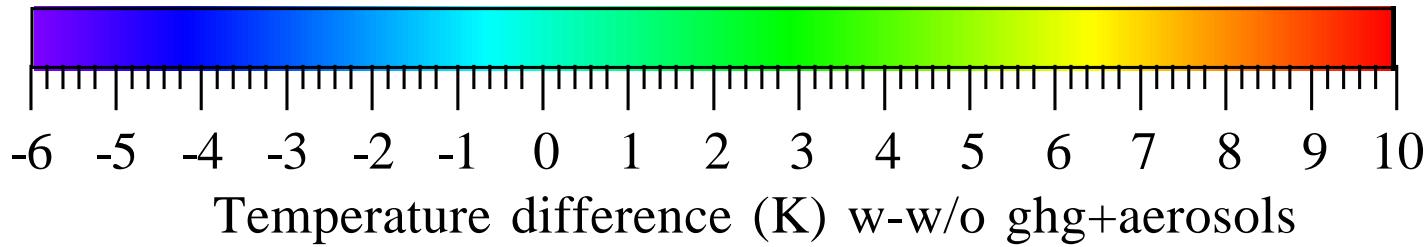
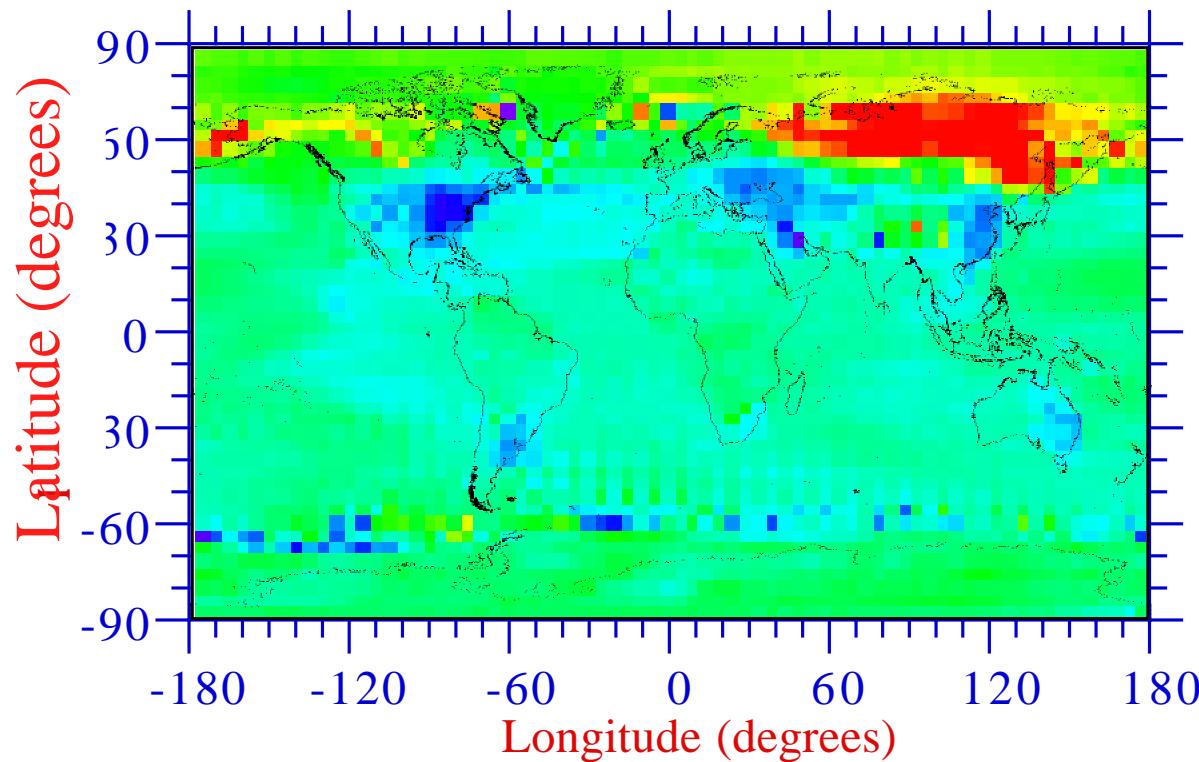


Observed and Modeled Temp. Diff. w-w/o GHG and Aerosols

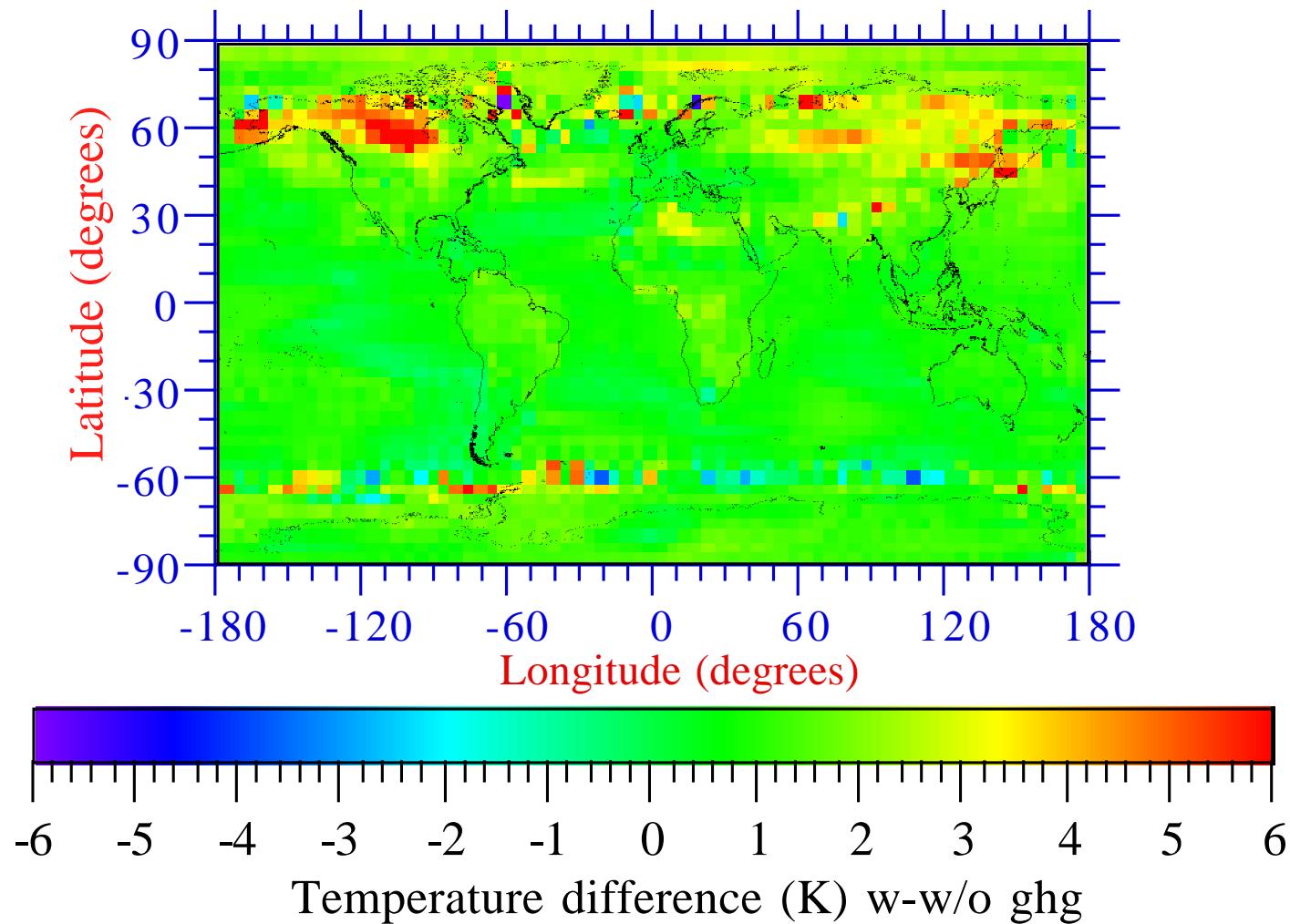
(January only)



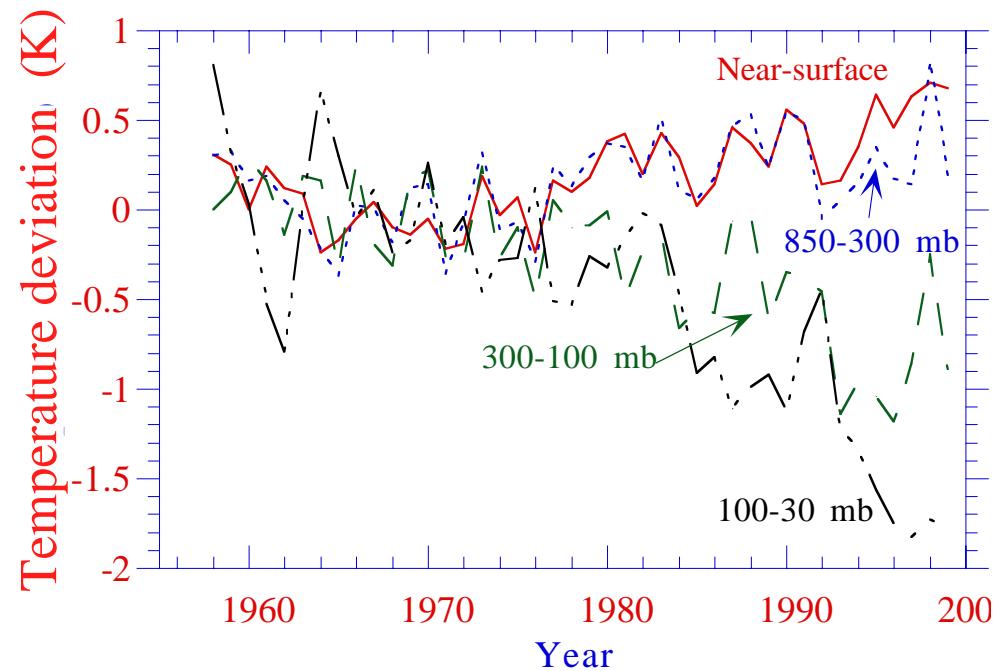
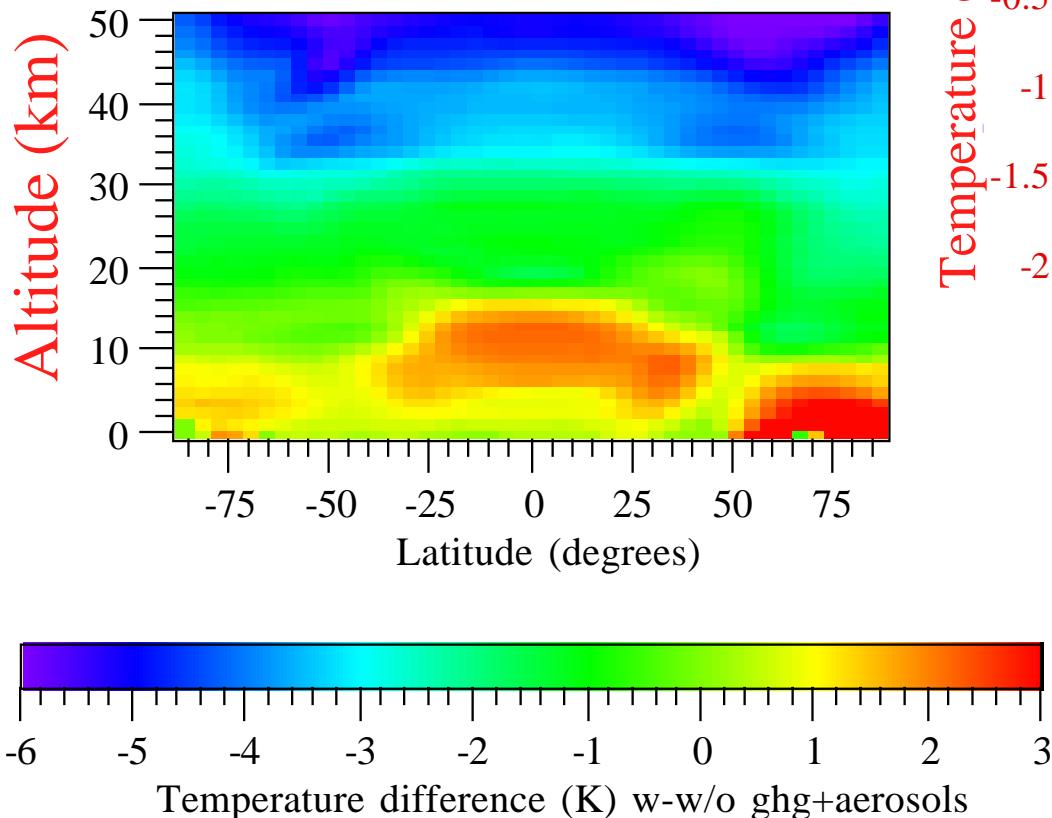
Schneider and Held (2001)



Modeled (4 y avg.) Temp. Diff. w-w/o Anth. GHG alone



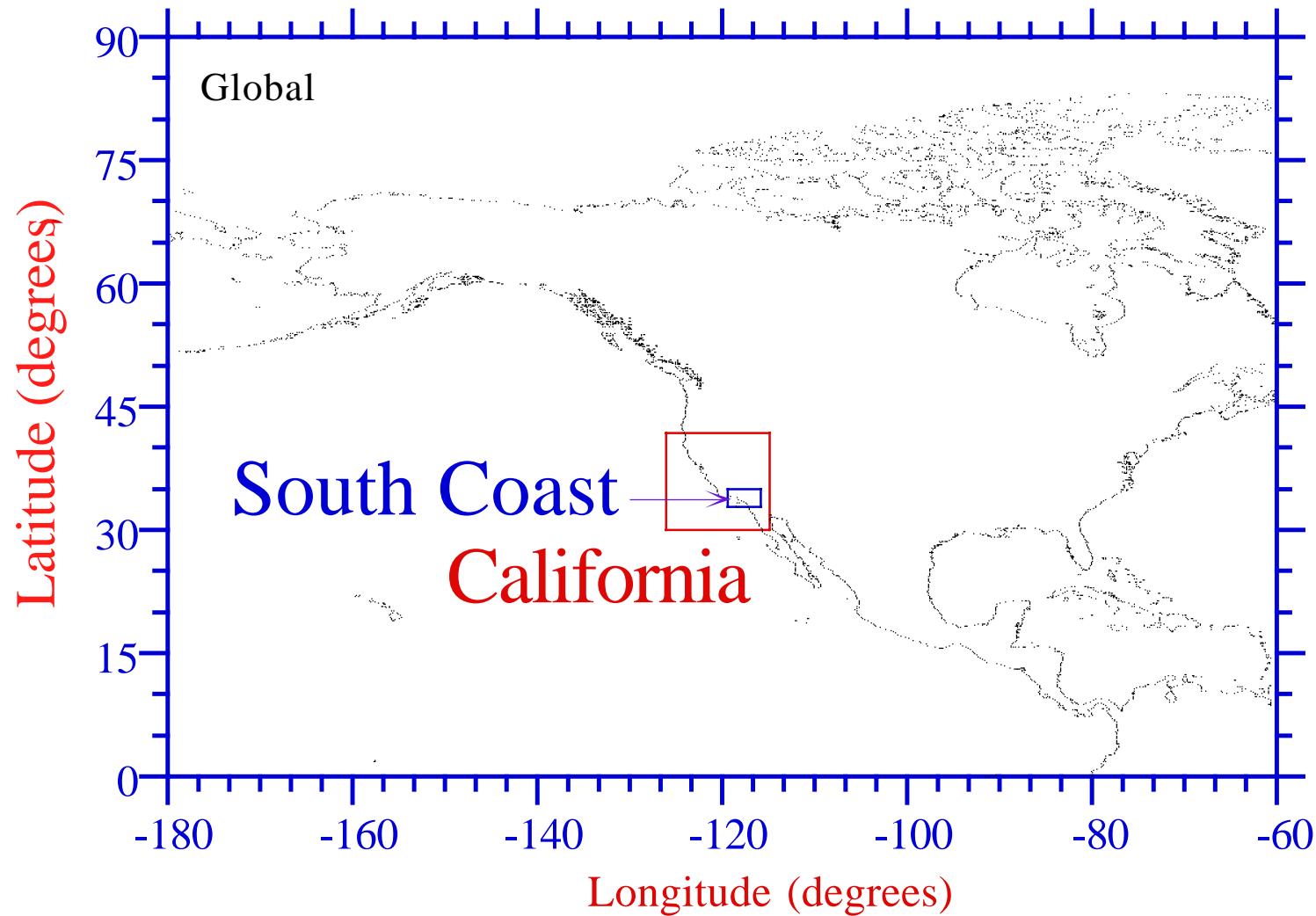
Modeled (4 y avg.) and Radiosonde Vertical Temp. (K) dif. w-w/o GHG and Aerosols



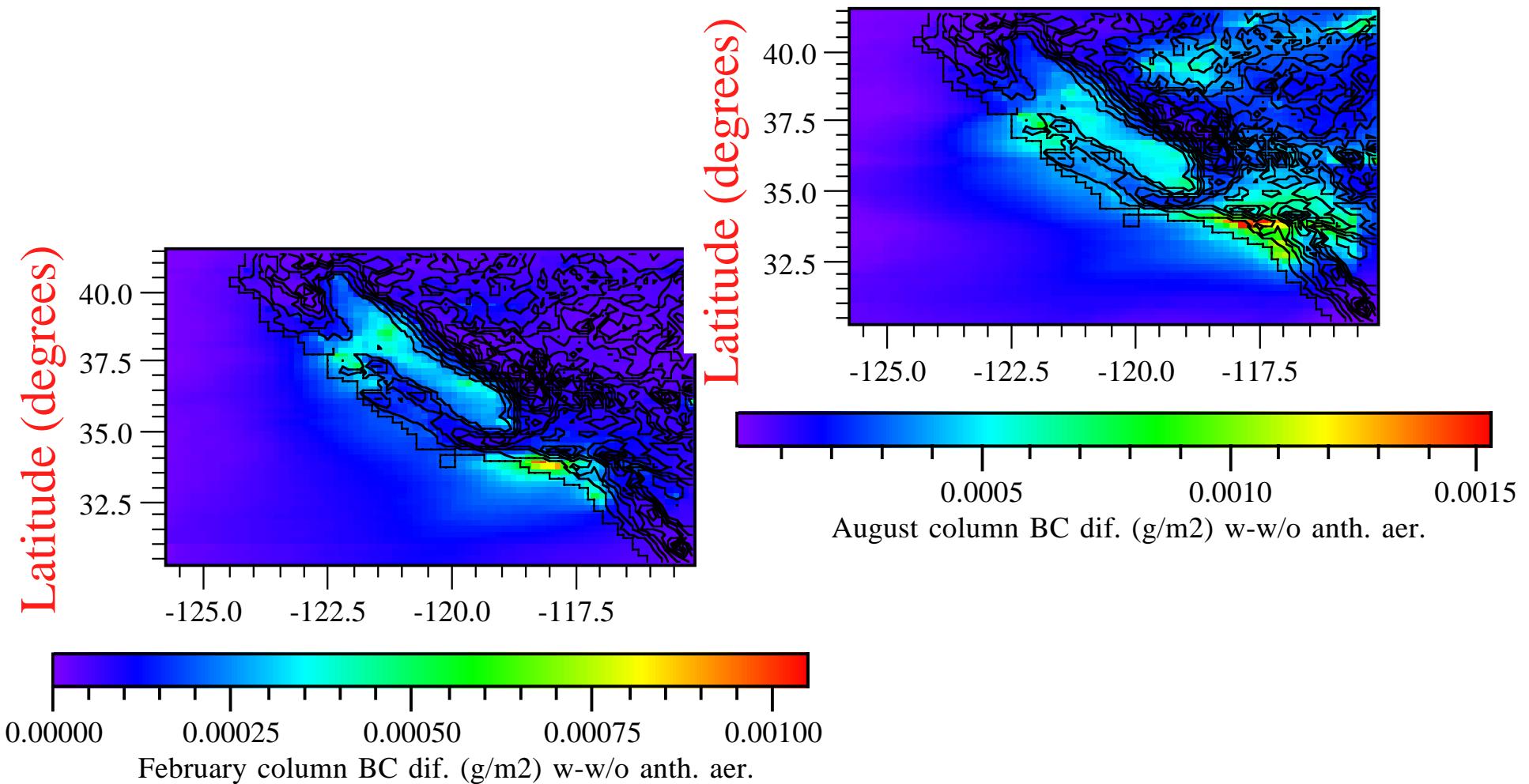
Radiosonde data
Angell et al. (1999)

300-100 mb \approx 9-16 km
100-30 mb \approx 16-24 km

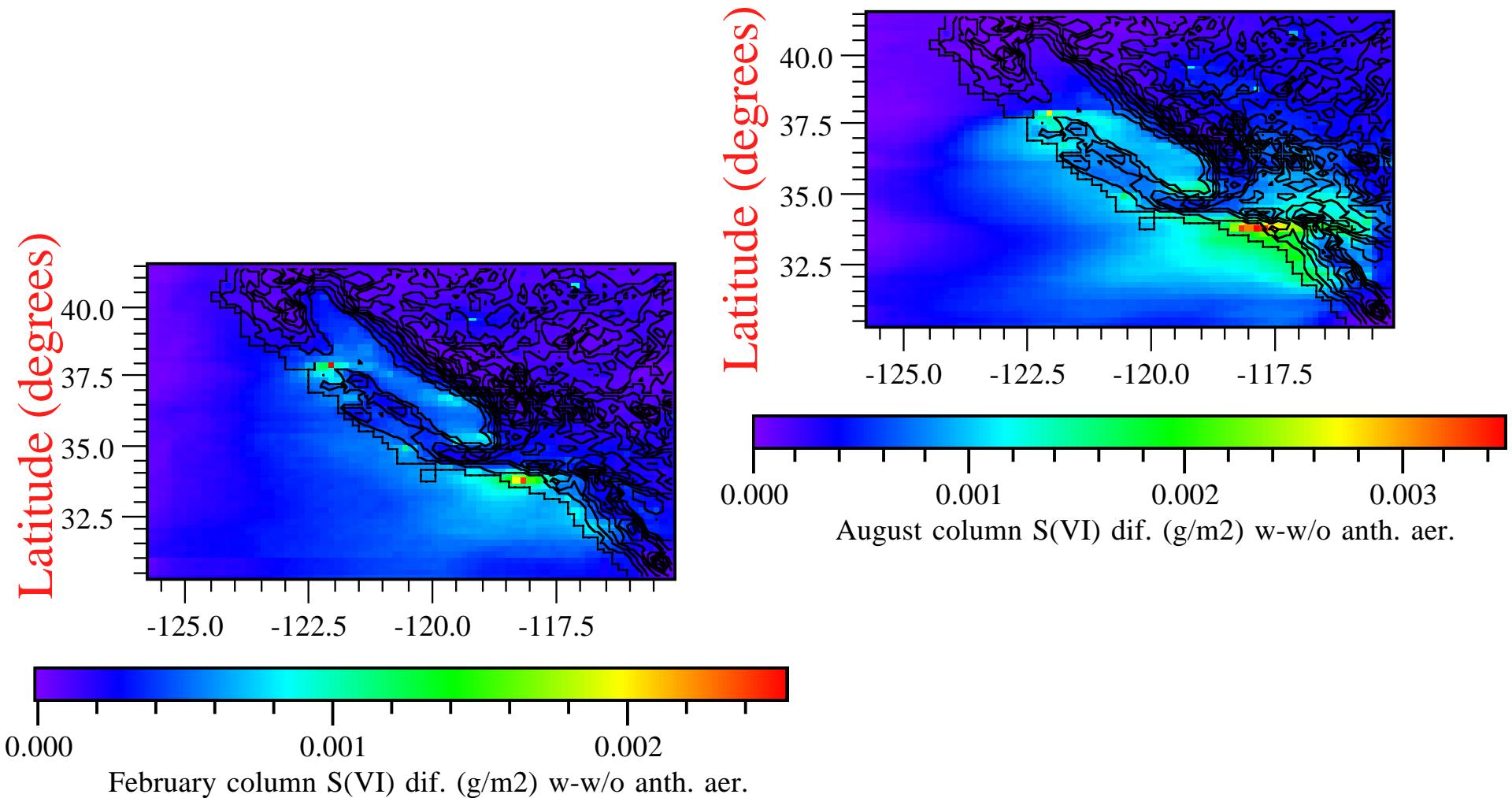
Model Grids Treated for California Case



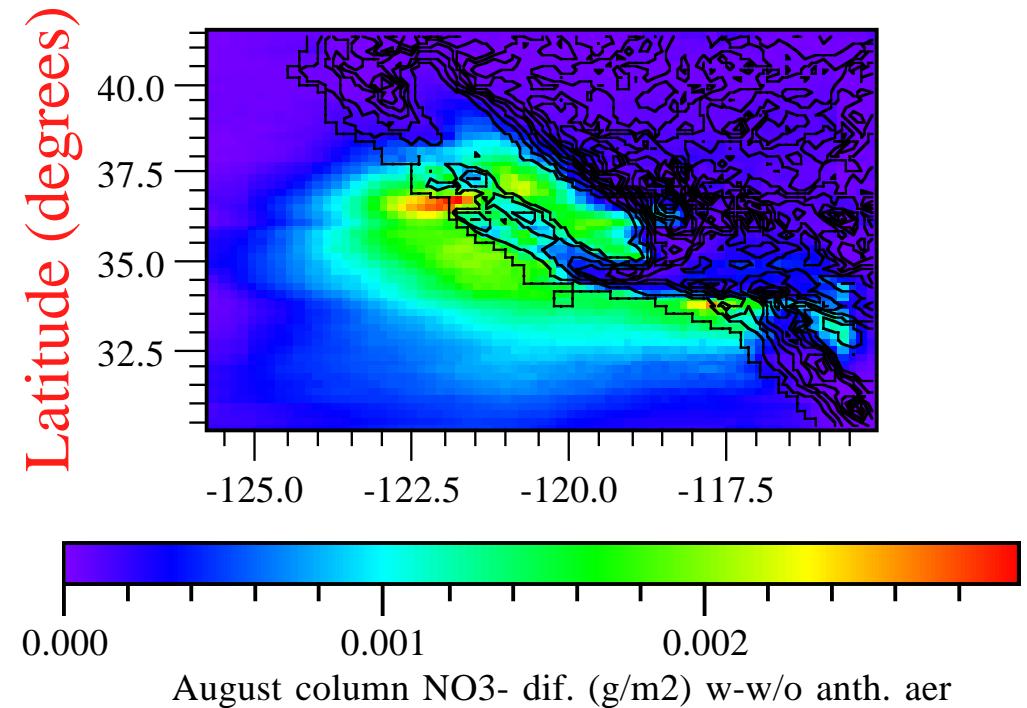
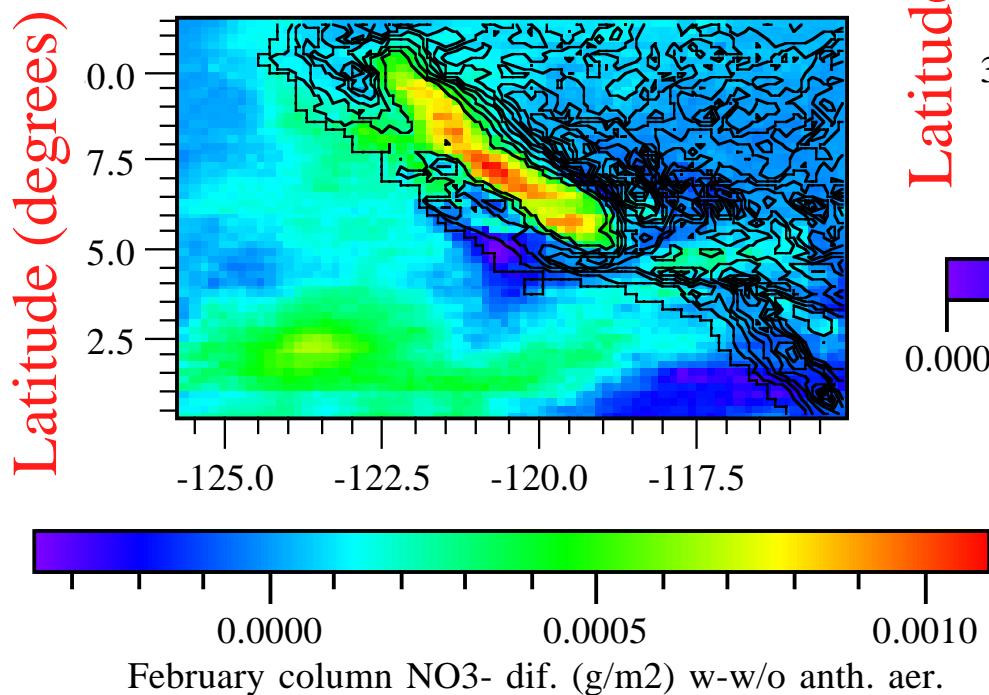
Feb. & Aug. California Column BC Dif. w-w/o Anth. Aer.



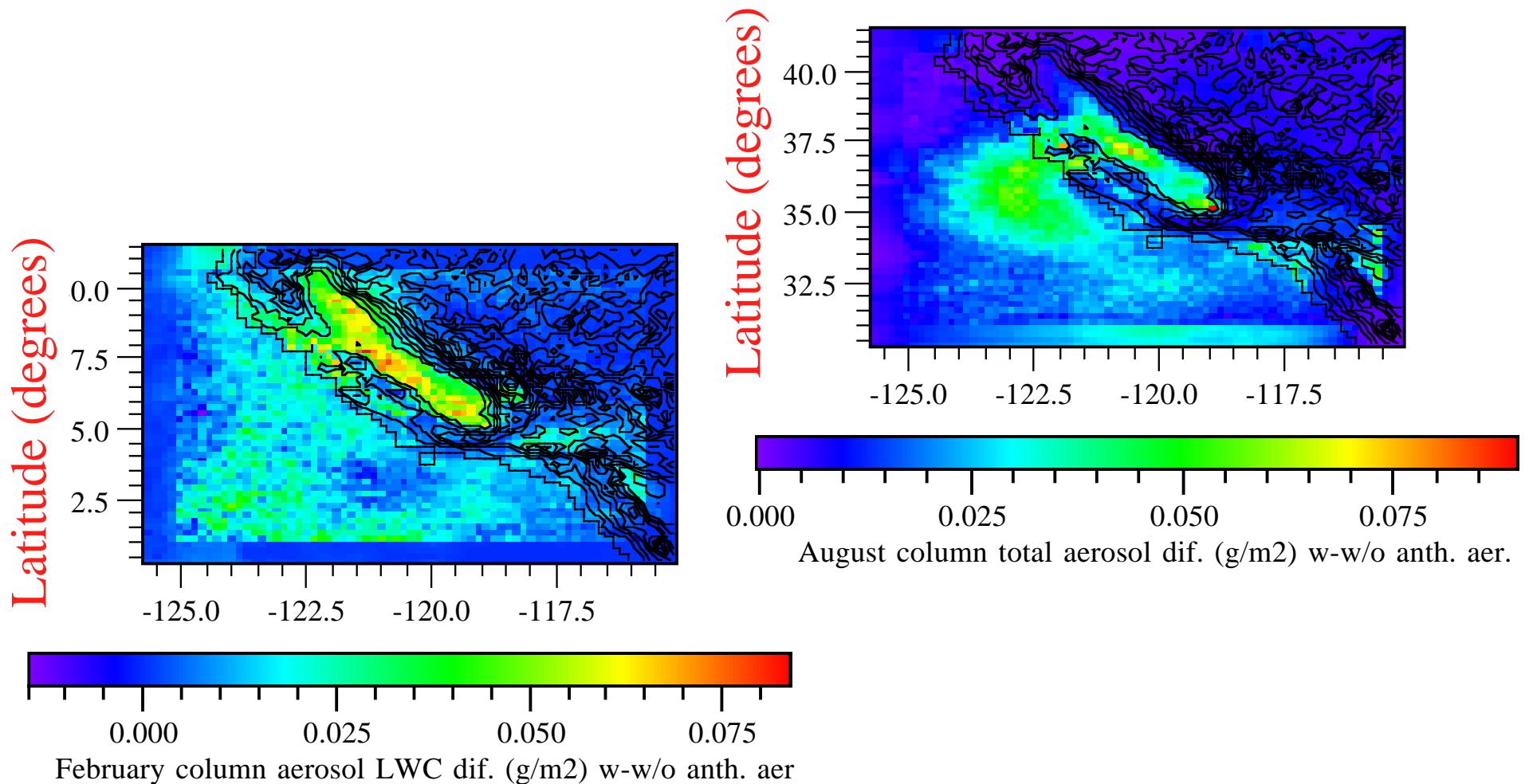
Column S(VI) Dif. w-w/o Anth. Aer.



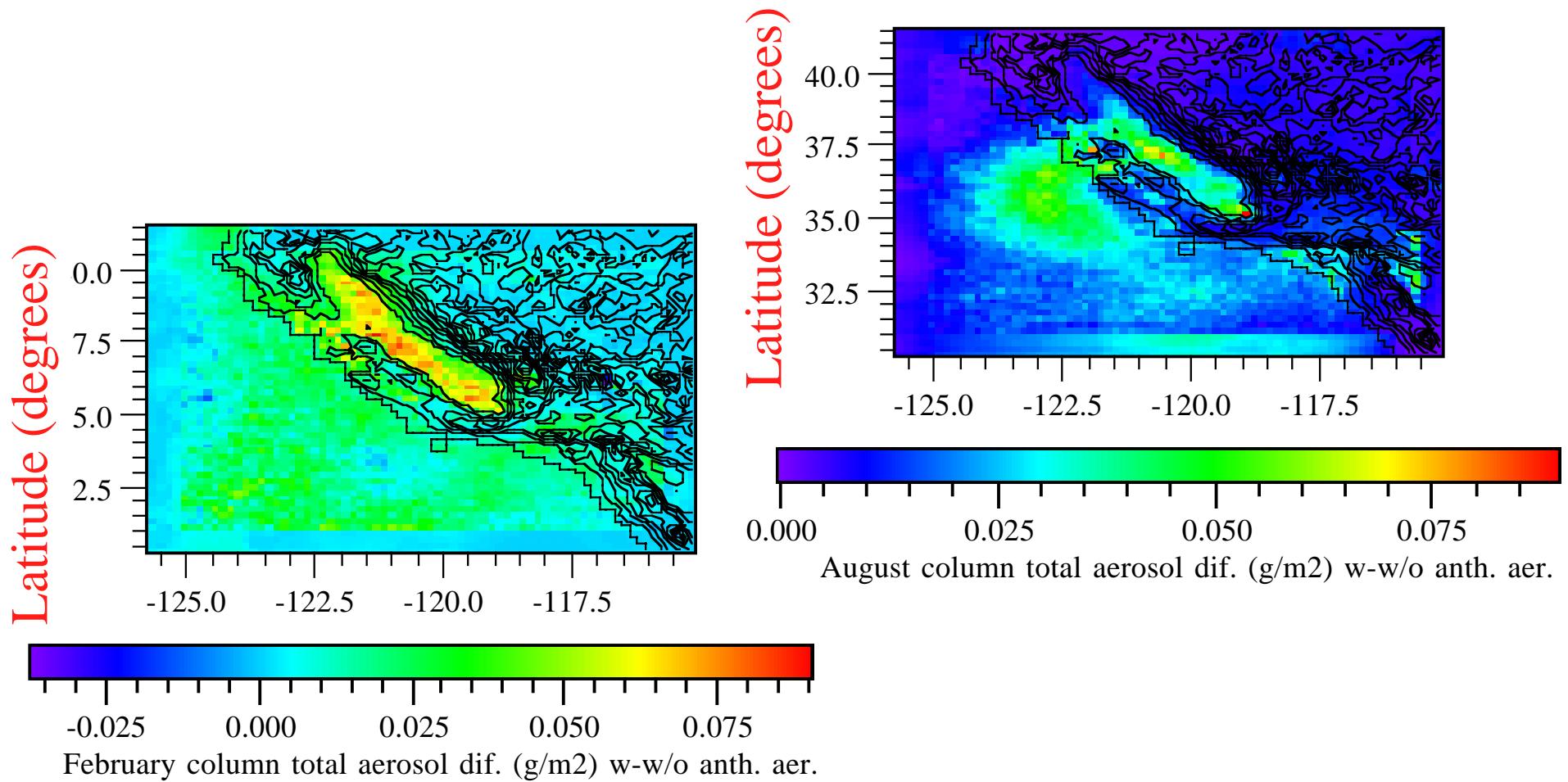
Column NO₃⁻ Dif. w-w/o Anth. Aer.



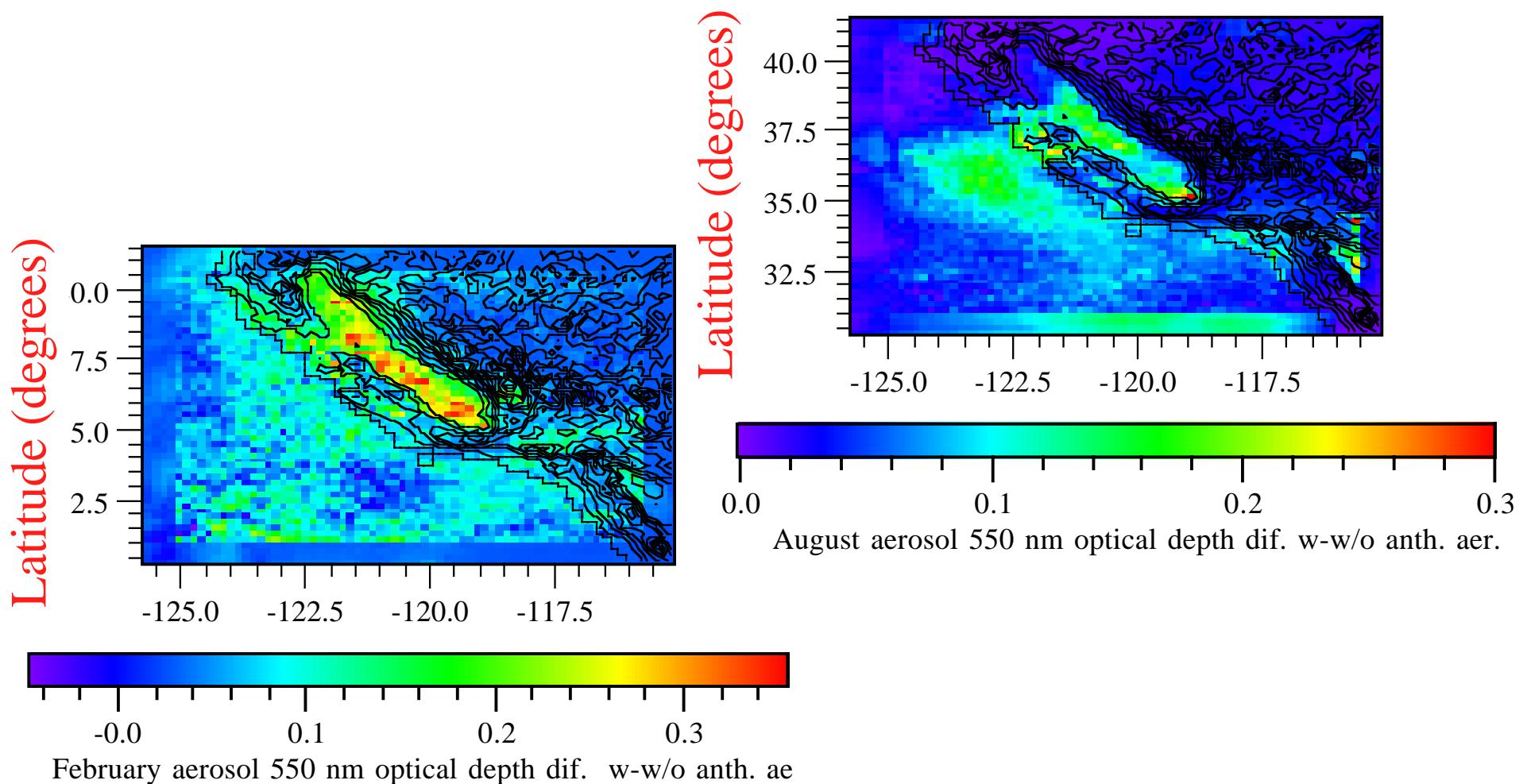
Column Aerosol LWC Dif. w-w/o Anth.Aer.



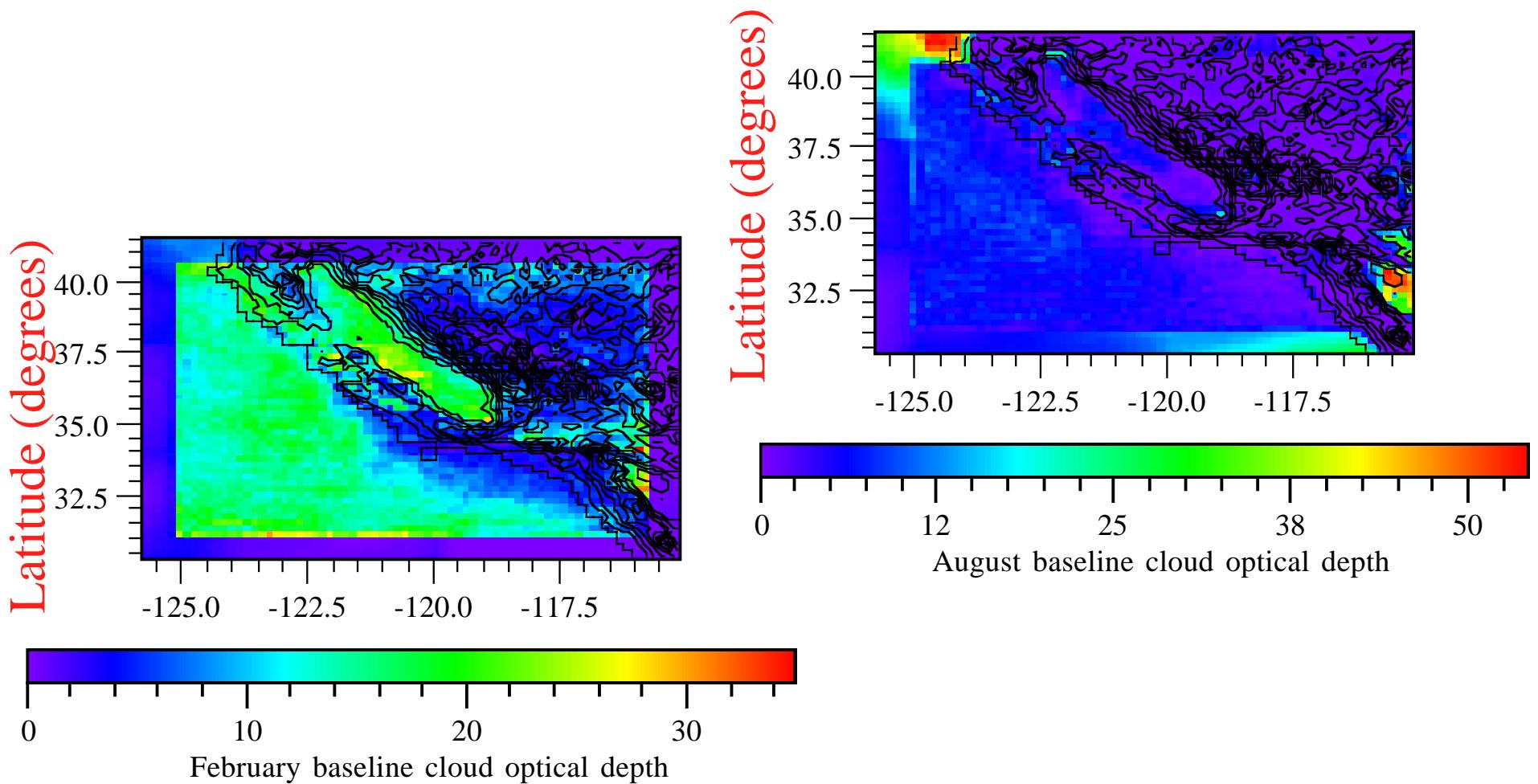
Column Total Aerosol Dif. w-w/o Anth. Aer.



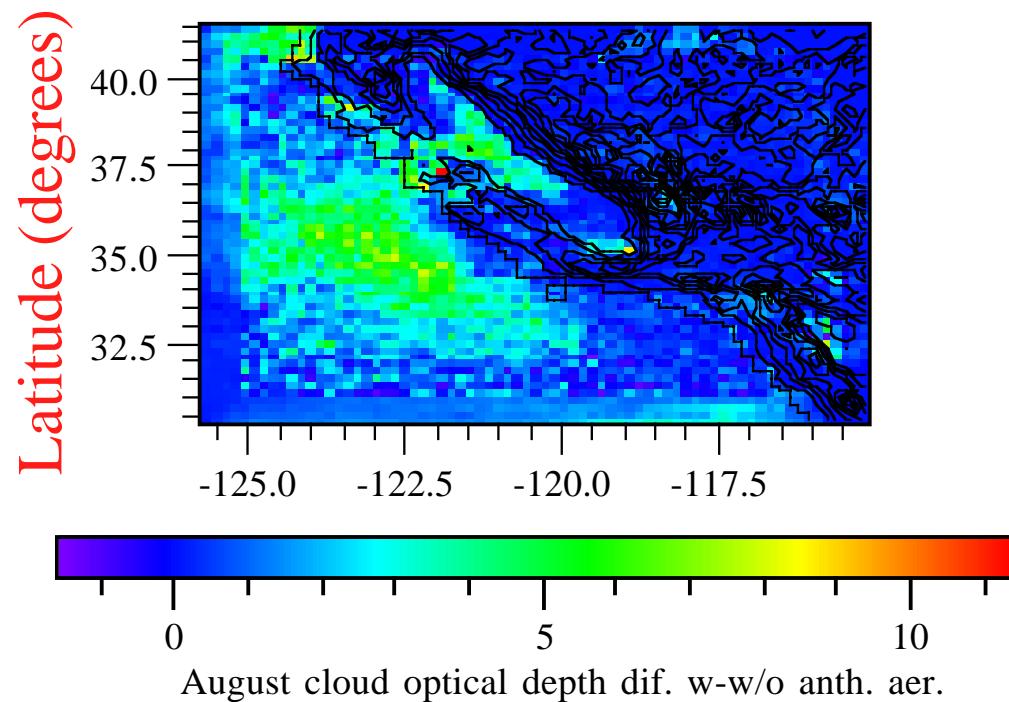
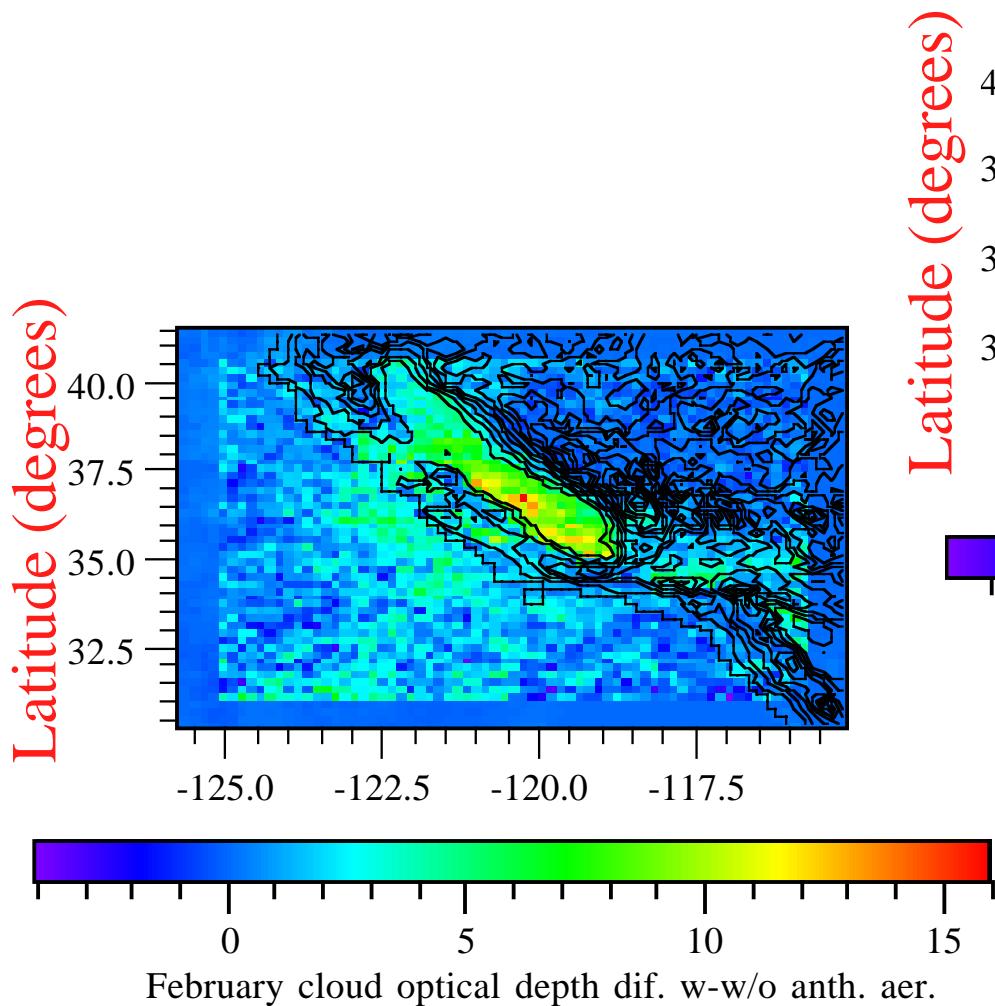
Aerosol 550 nm Optical Depth Dif. w-w/o Anth.Aer.



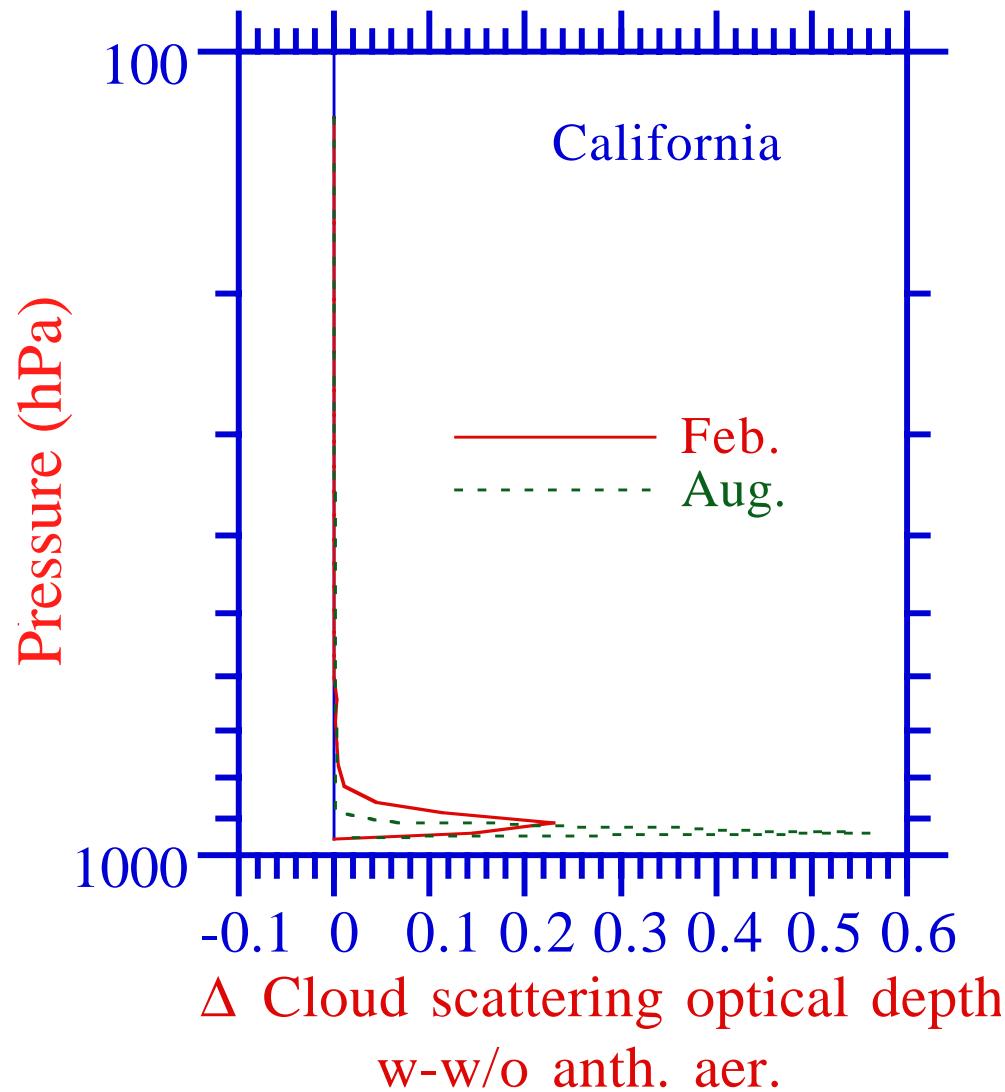
Baseline Cloud 550 nm Optical Depth



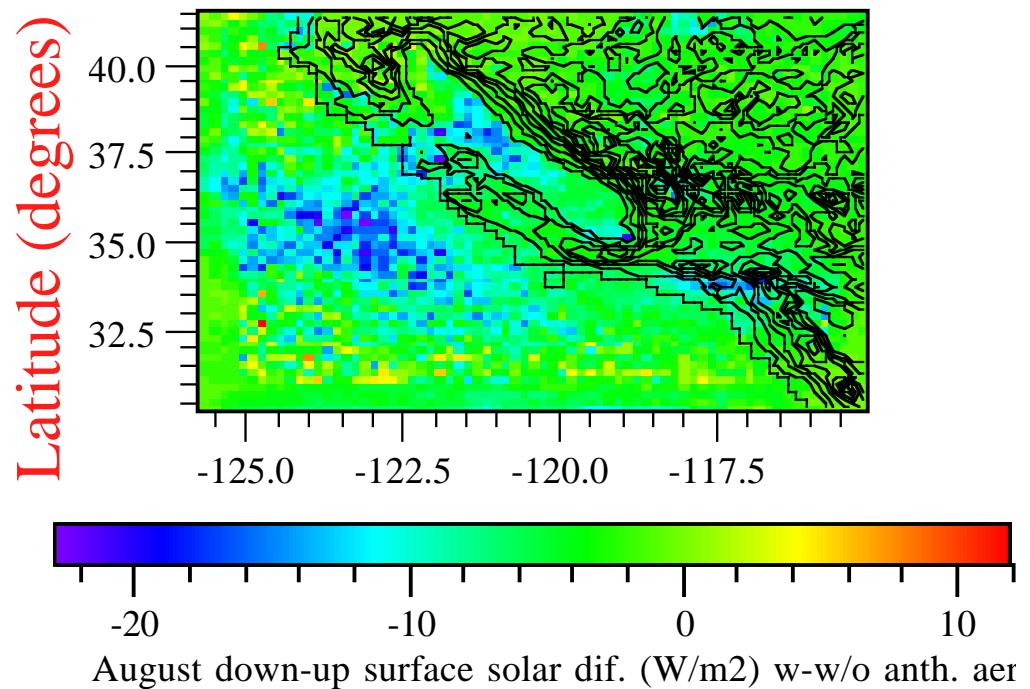
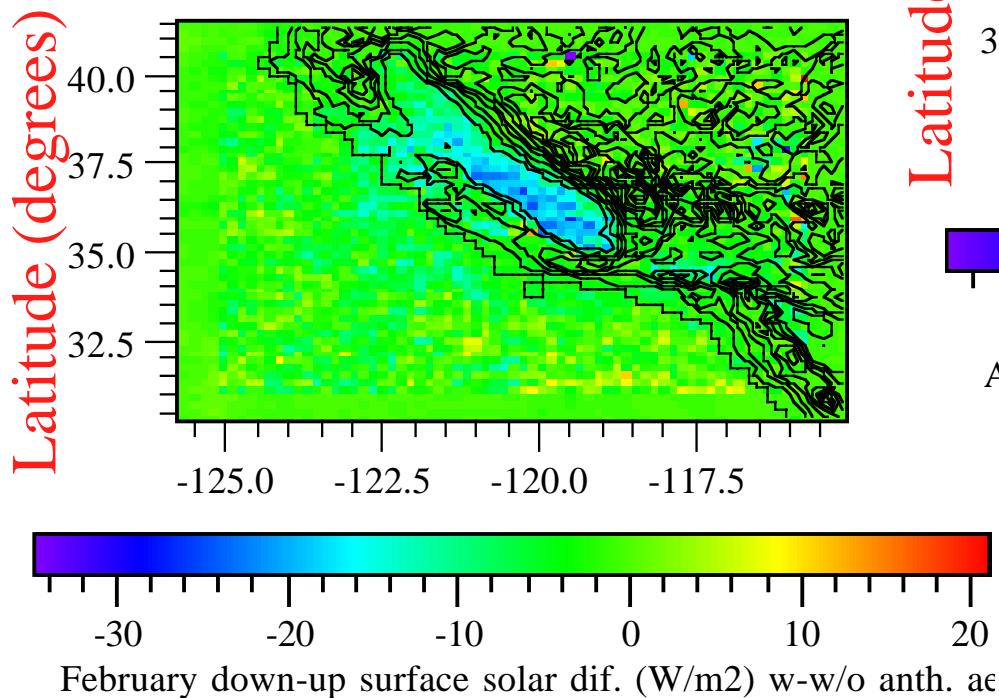
Cloud 550 nm Optical Depth Dif. w-w/o Anth.Aer.



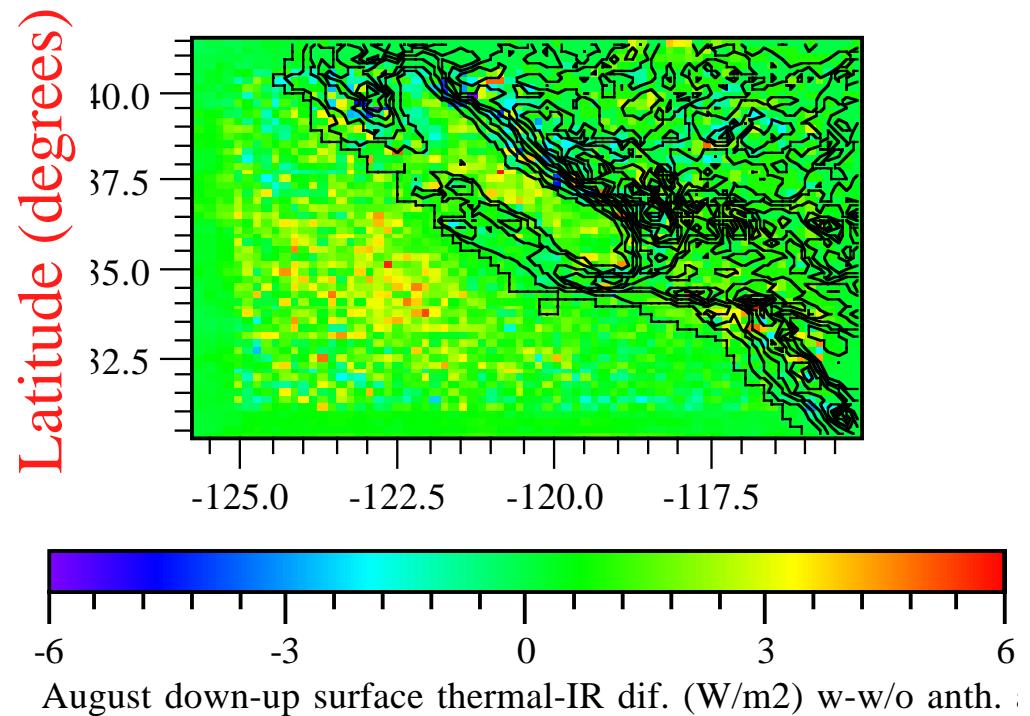
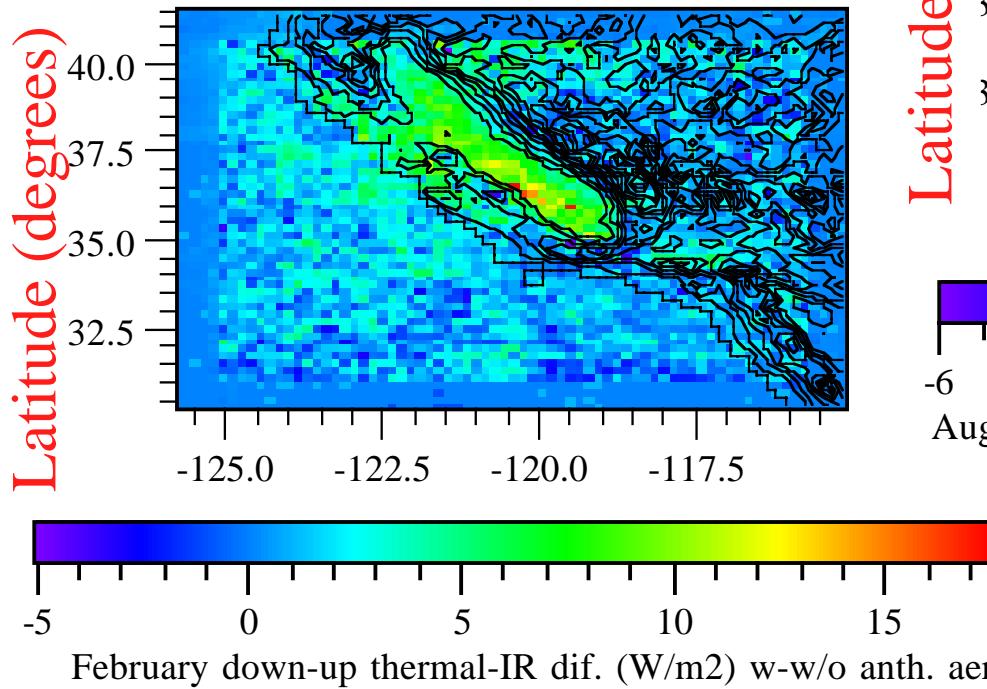
Cloud 550 nm Scattering Optical Depth Profile Dif.



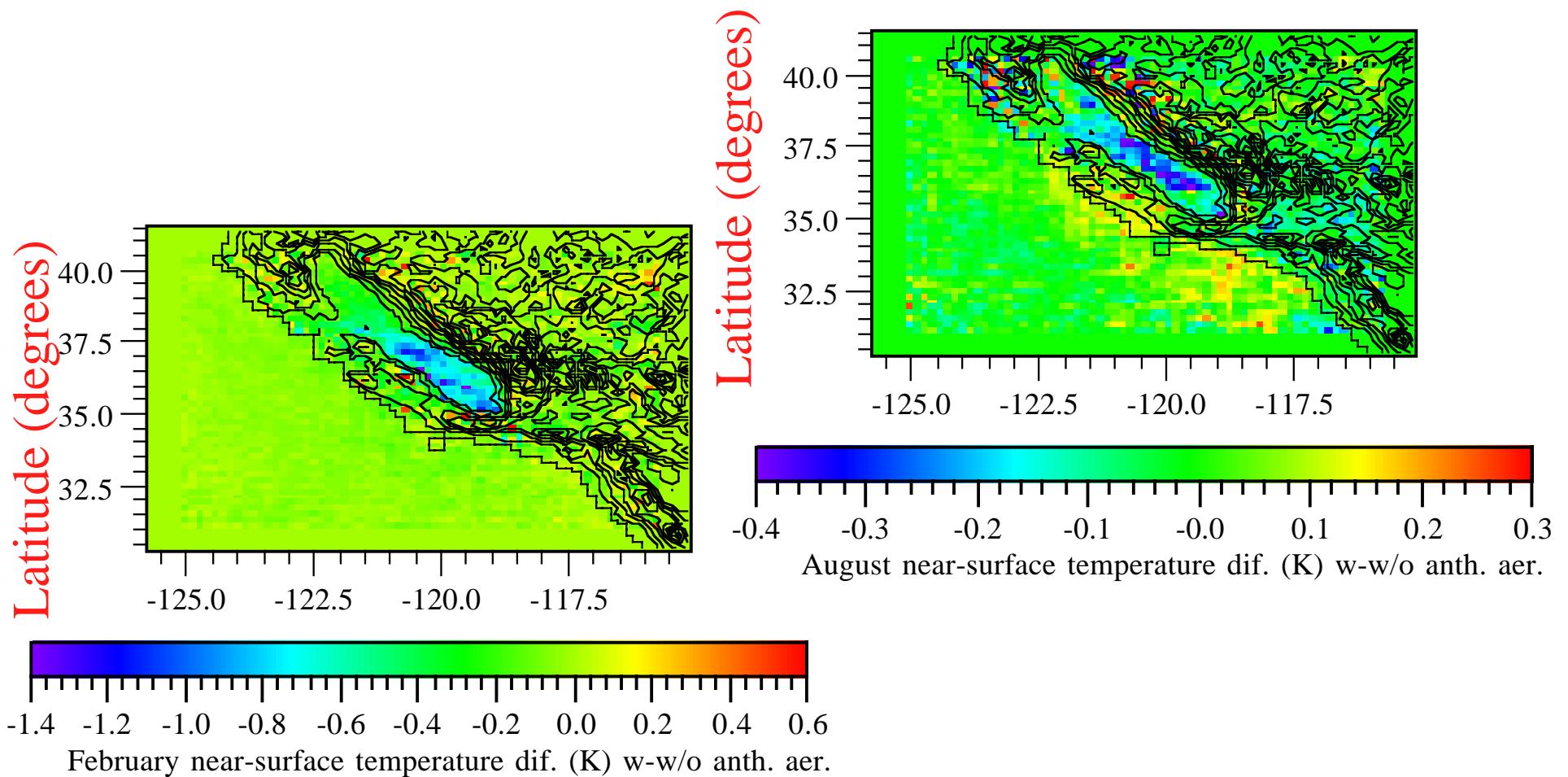
Down-Up Surface Solar Radiation Dif. w-w/o Anth.Aer.



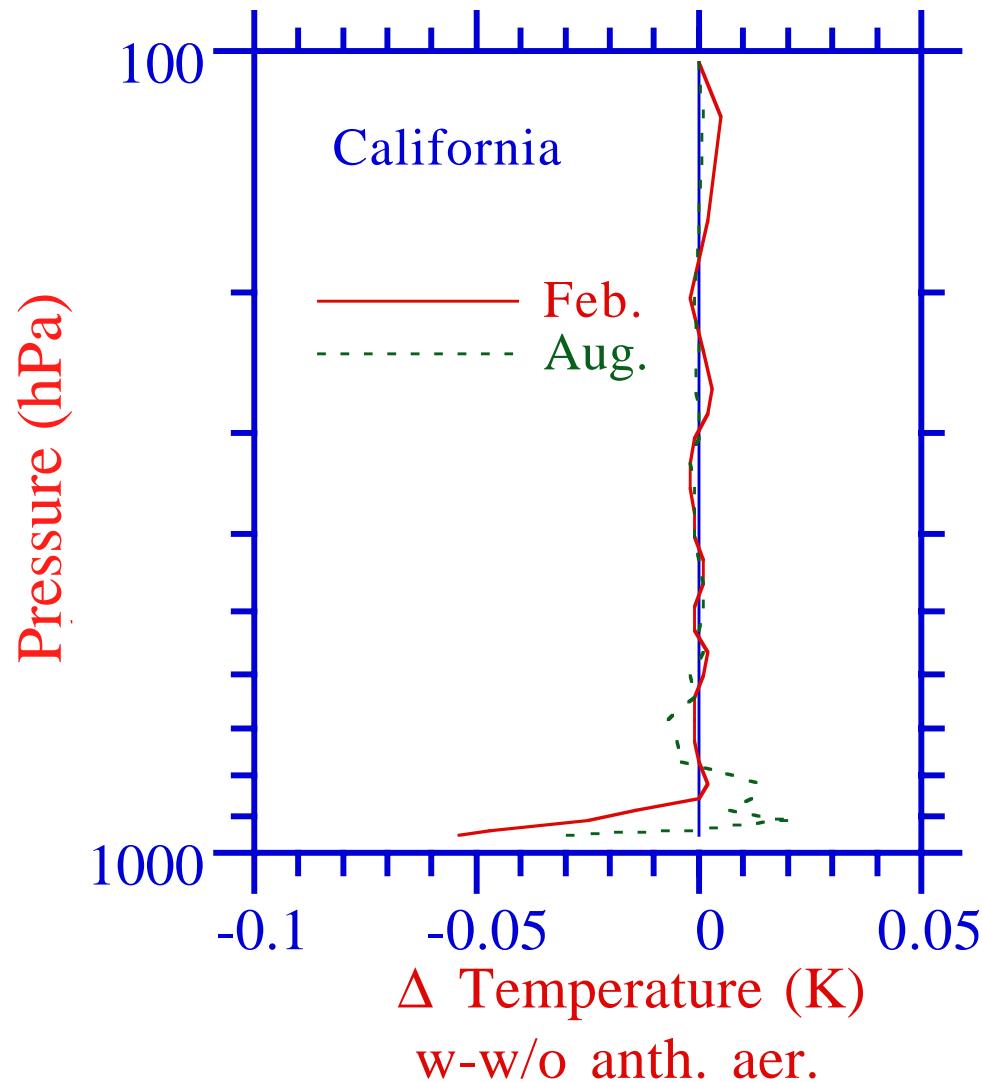
Down-Up Surface Thermal-IR Radiation Dif. w-w/o Anth.Aer.



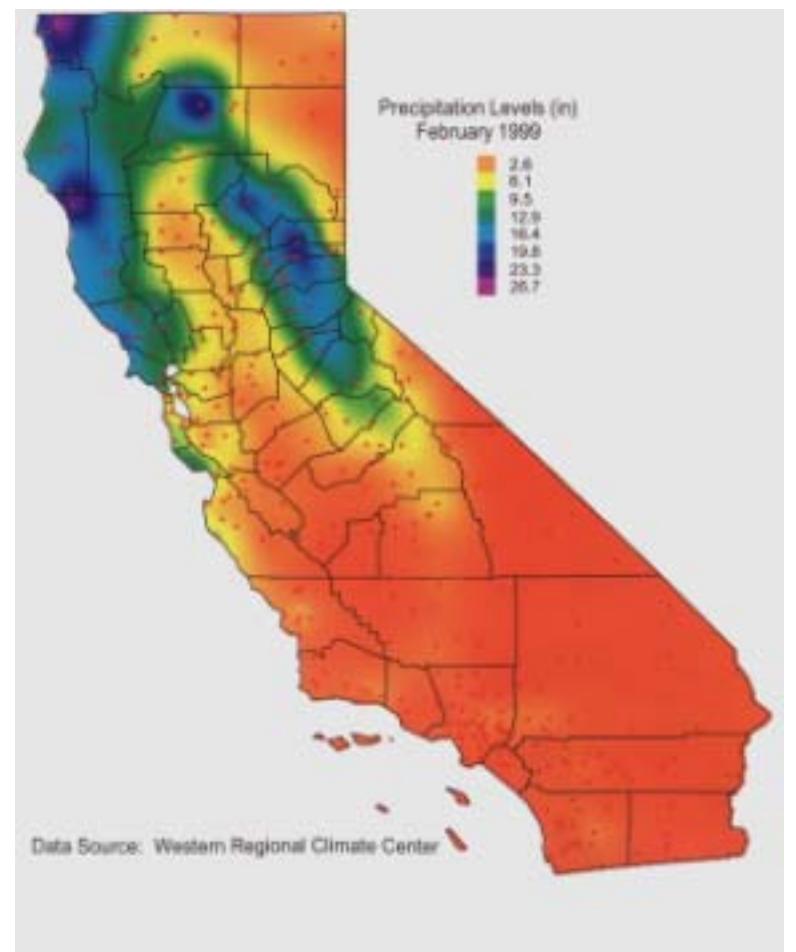
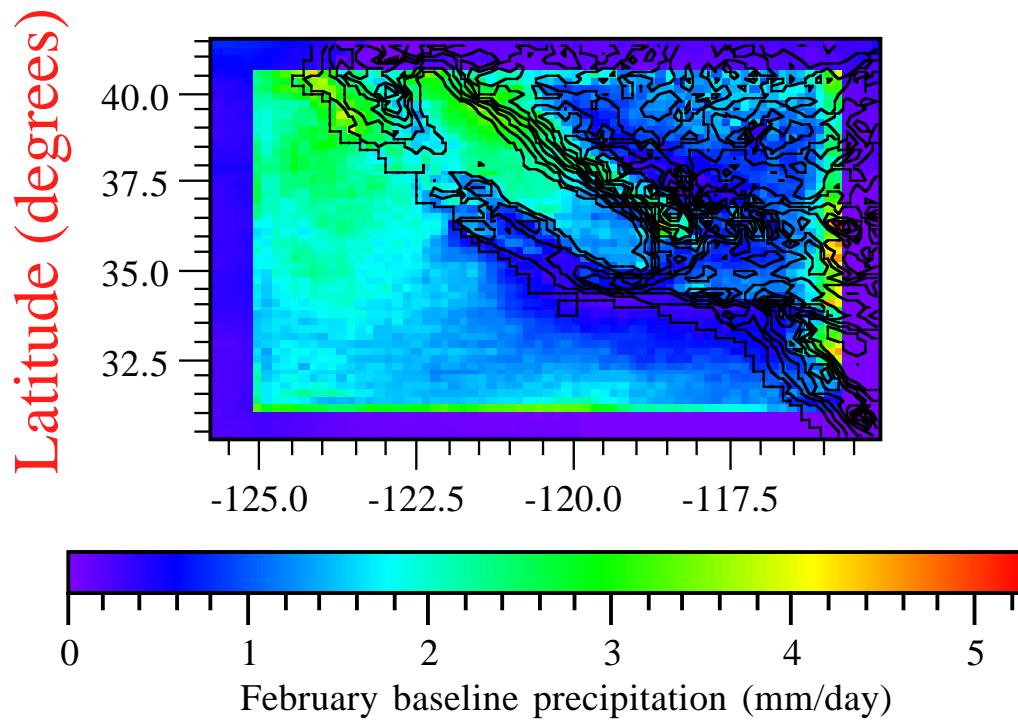
Near-surface Temperature Dif. w-w/o Anth.Aer.



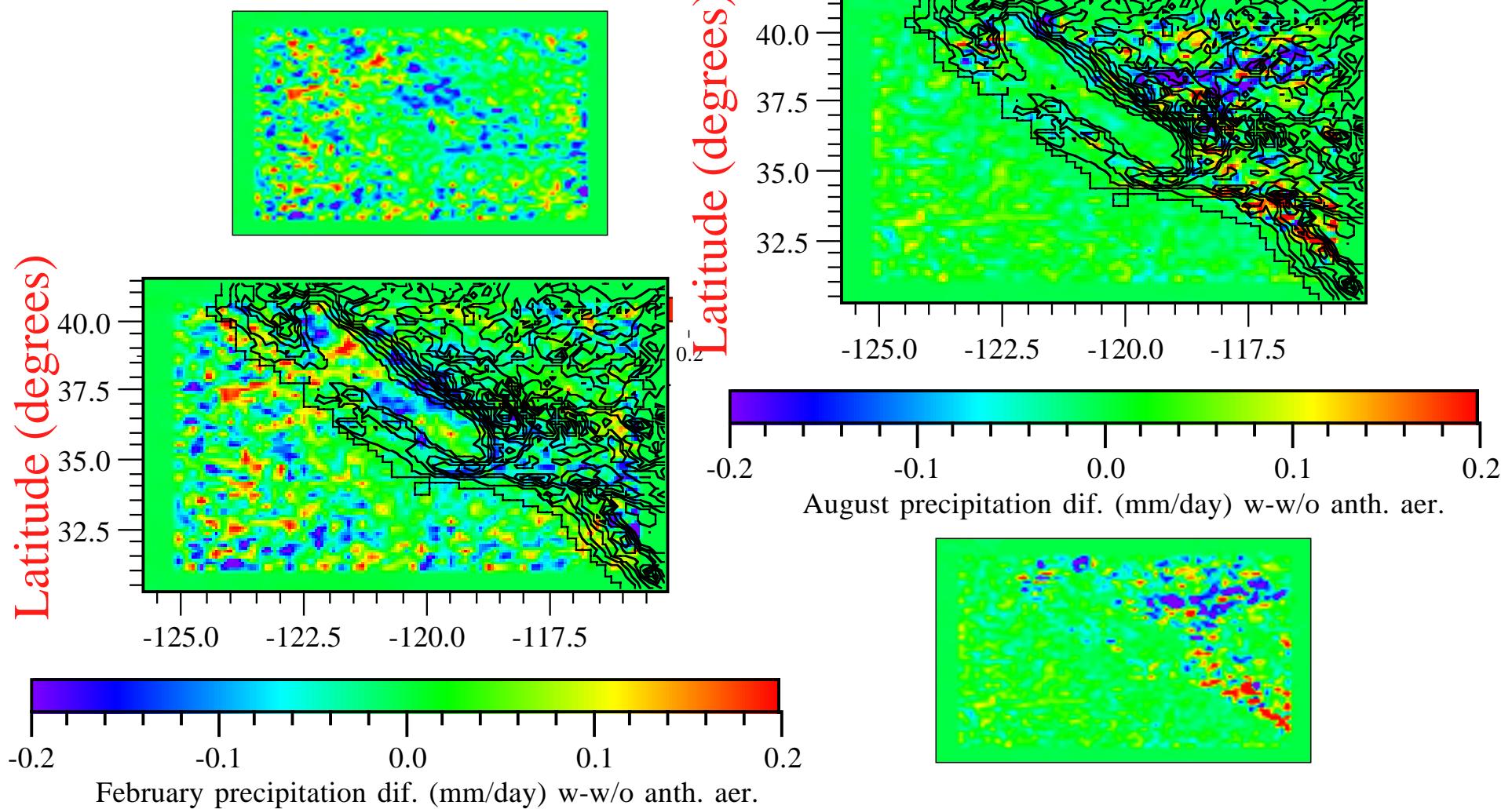
Temperature Profile Dif. Over California



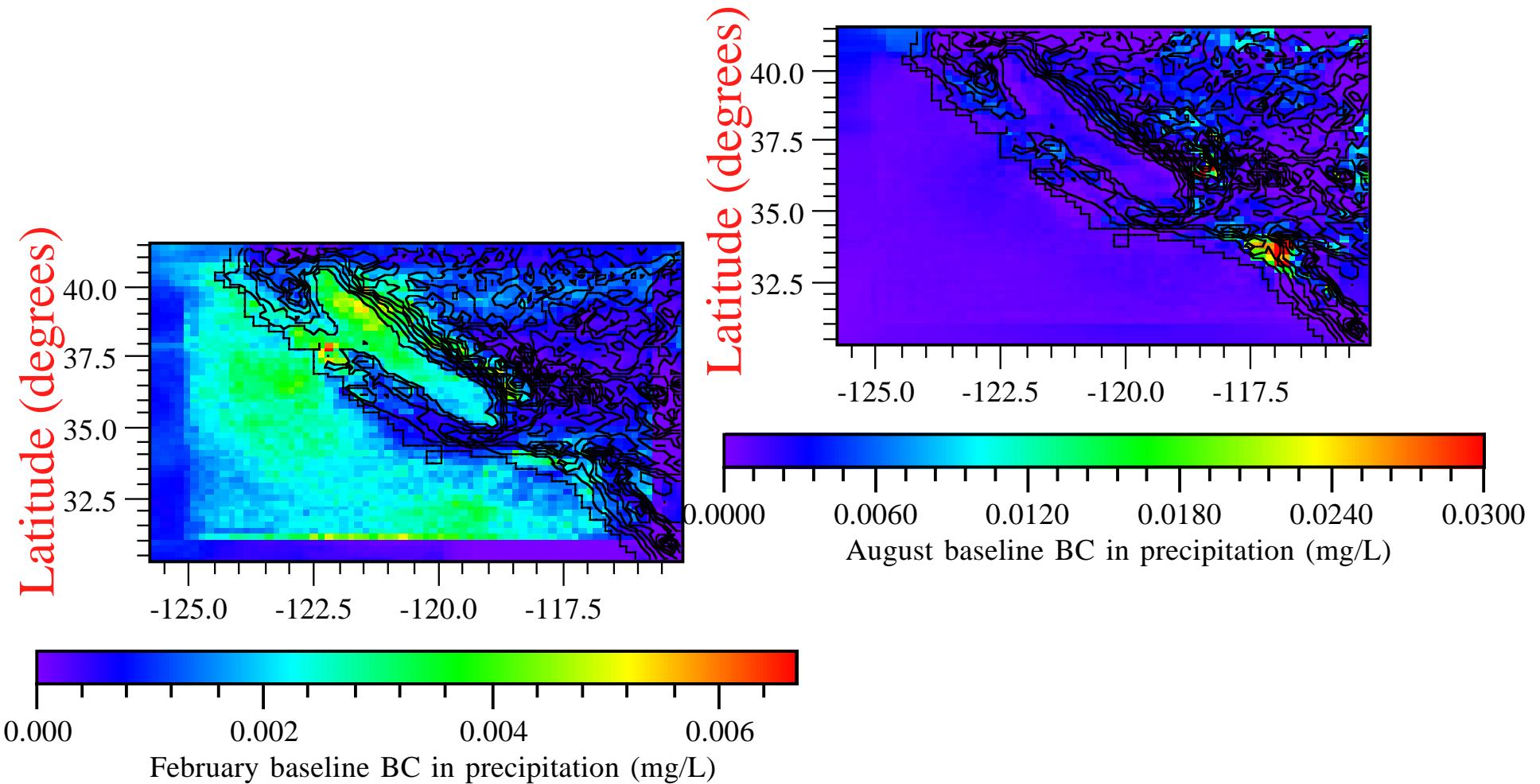
Modeled vs. Measured Feb. 1999 Precipitation



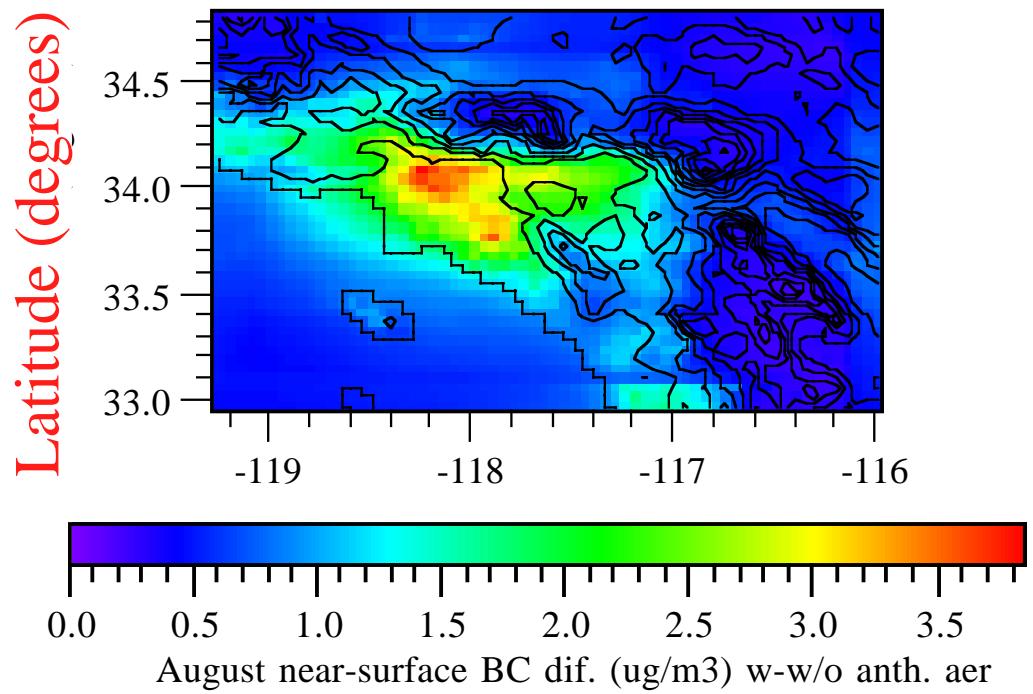
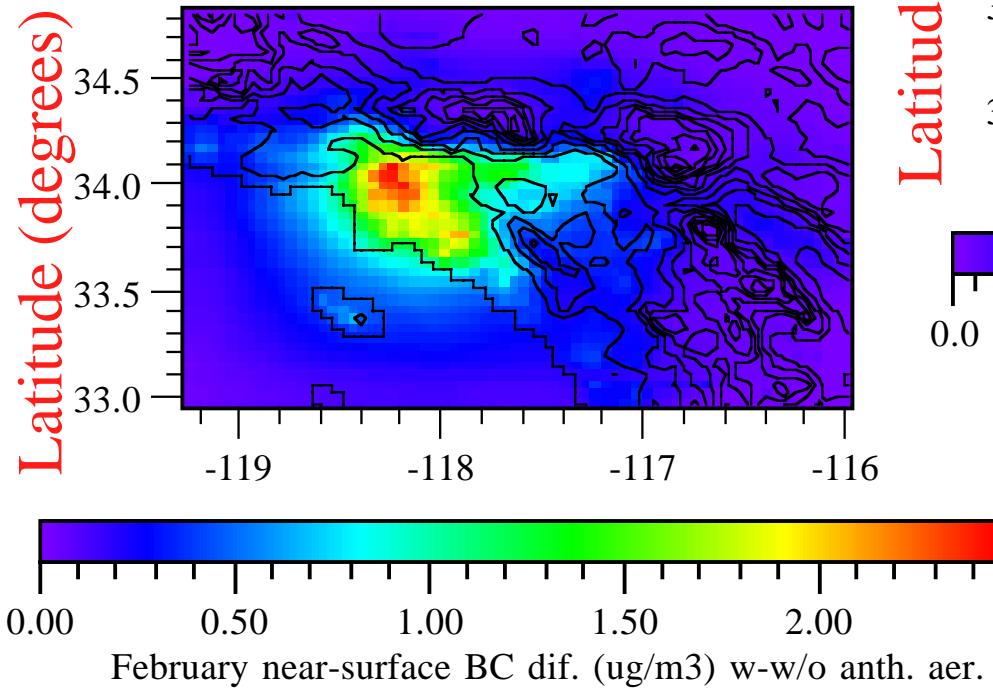
Precipitation Dif. w-w/o Anth.Aer.



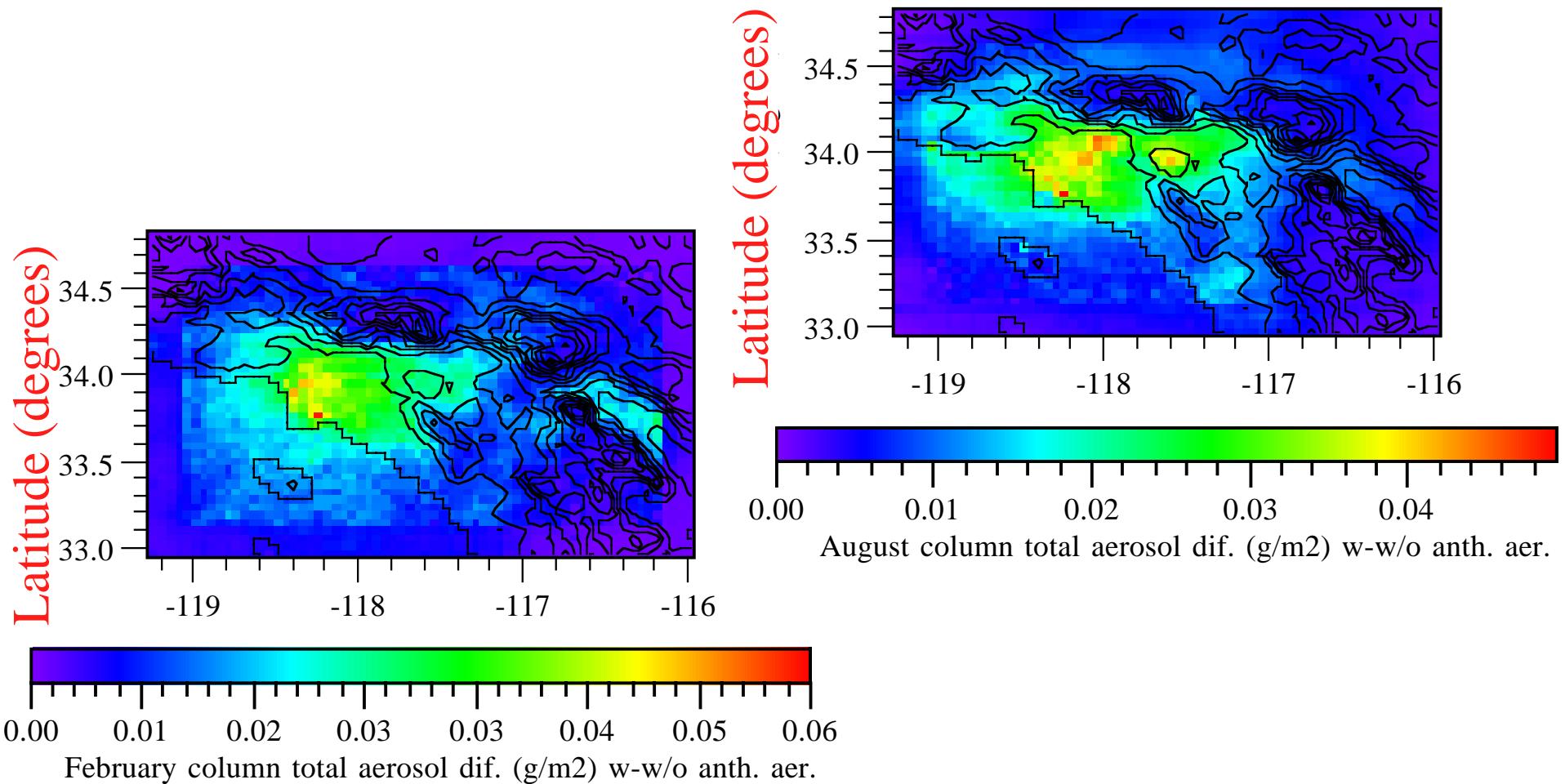
Baseline BC in Fog and Precipitation



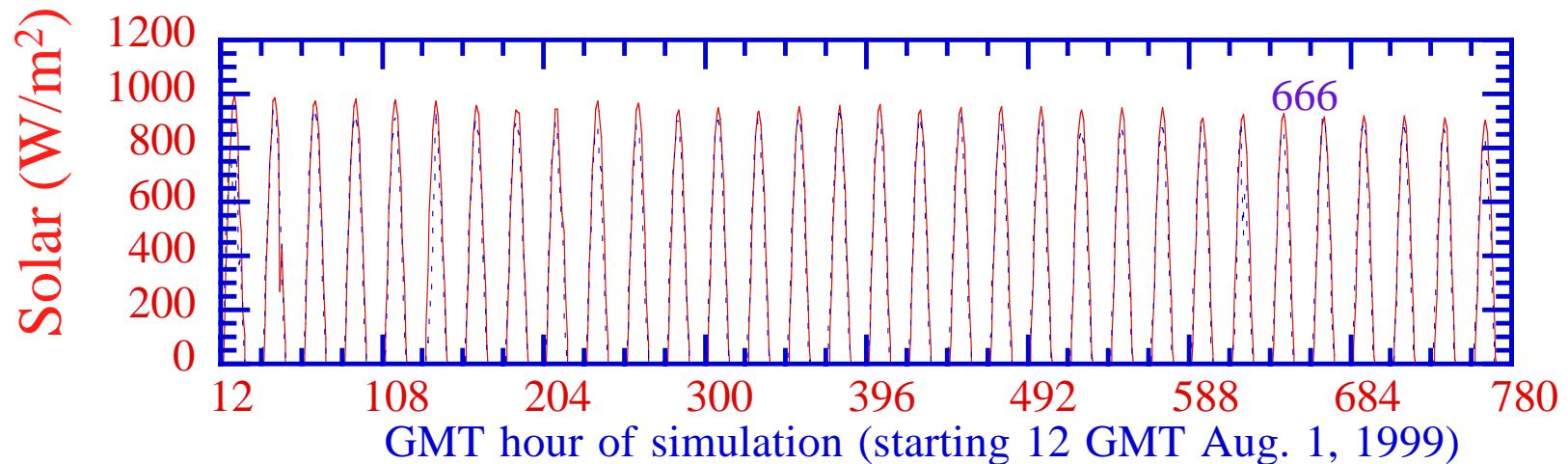
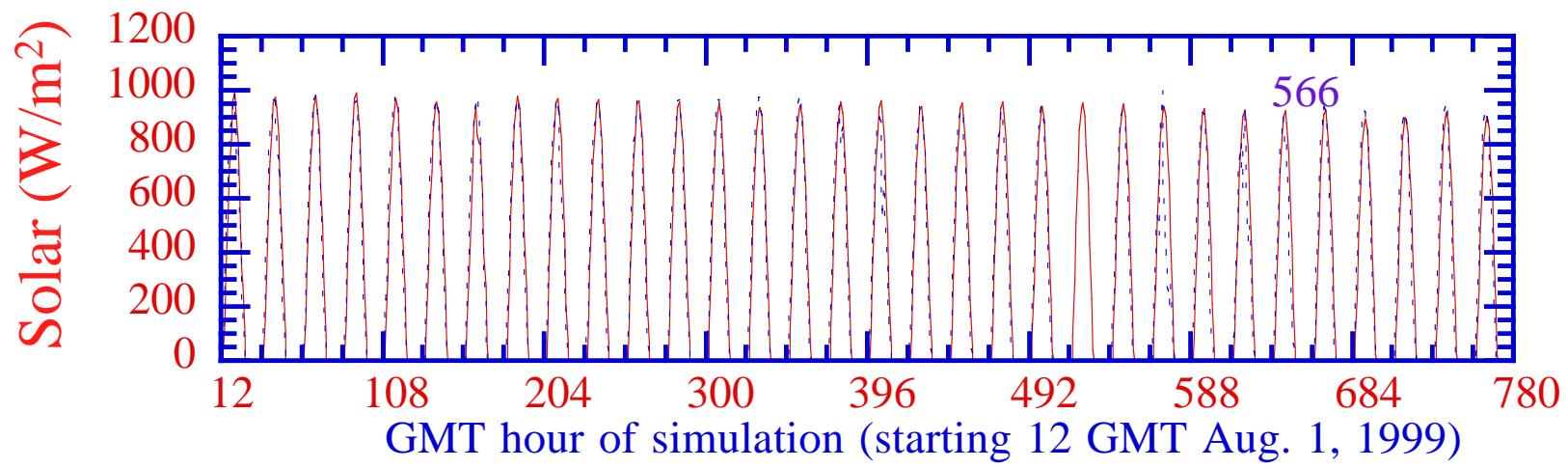
SCAB BC Dif. w-w/o Anth.Aer.



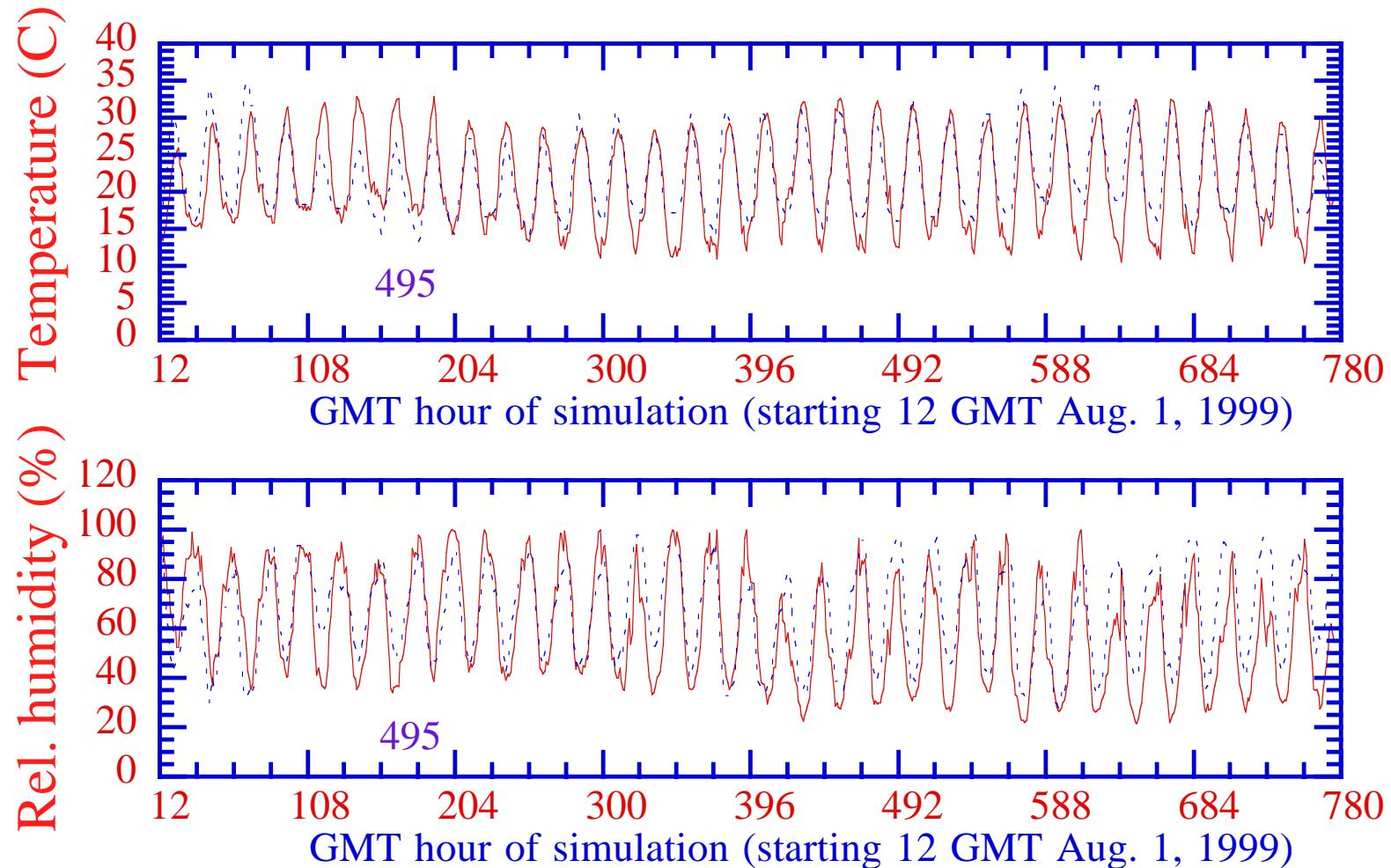
SCAB Column Total Aerosol Dif. w-w/o Anth.Aer.



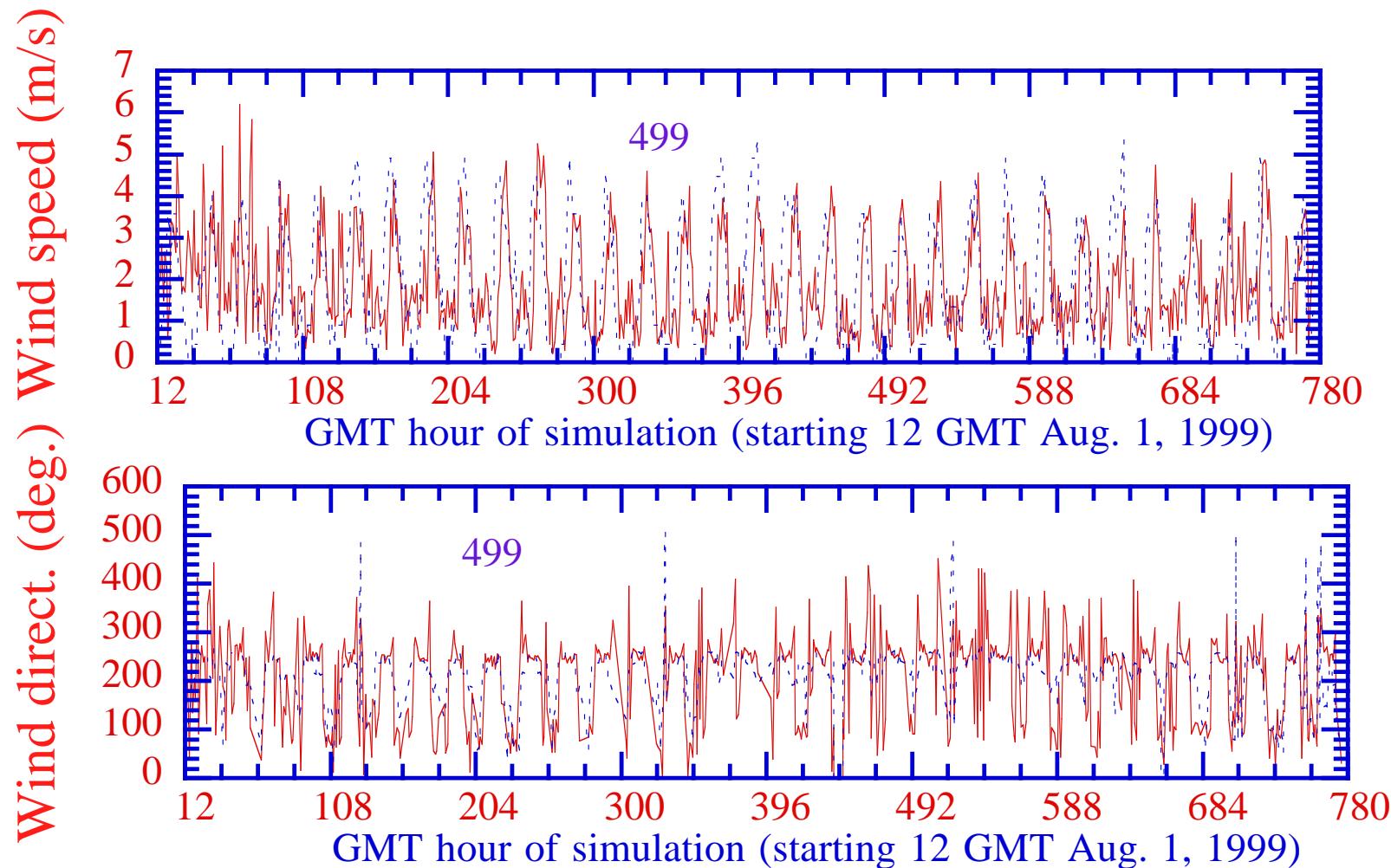
Paired-in-Time-and-Space Modeled (Red) v. Measured Solar Radiation



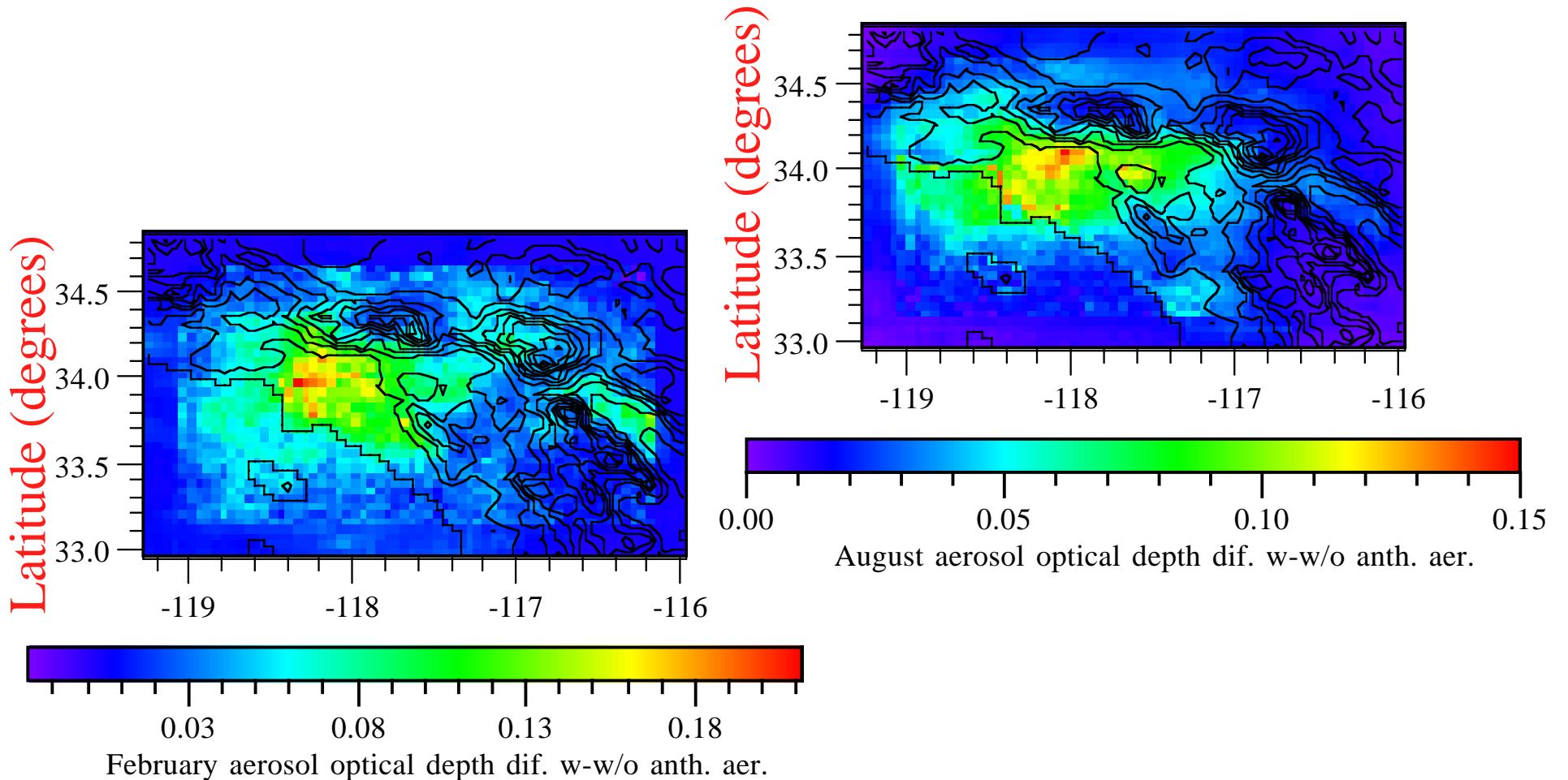
Paired-in-Time-and-Space Modeled (Red) v. Measured T and RH



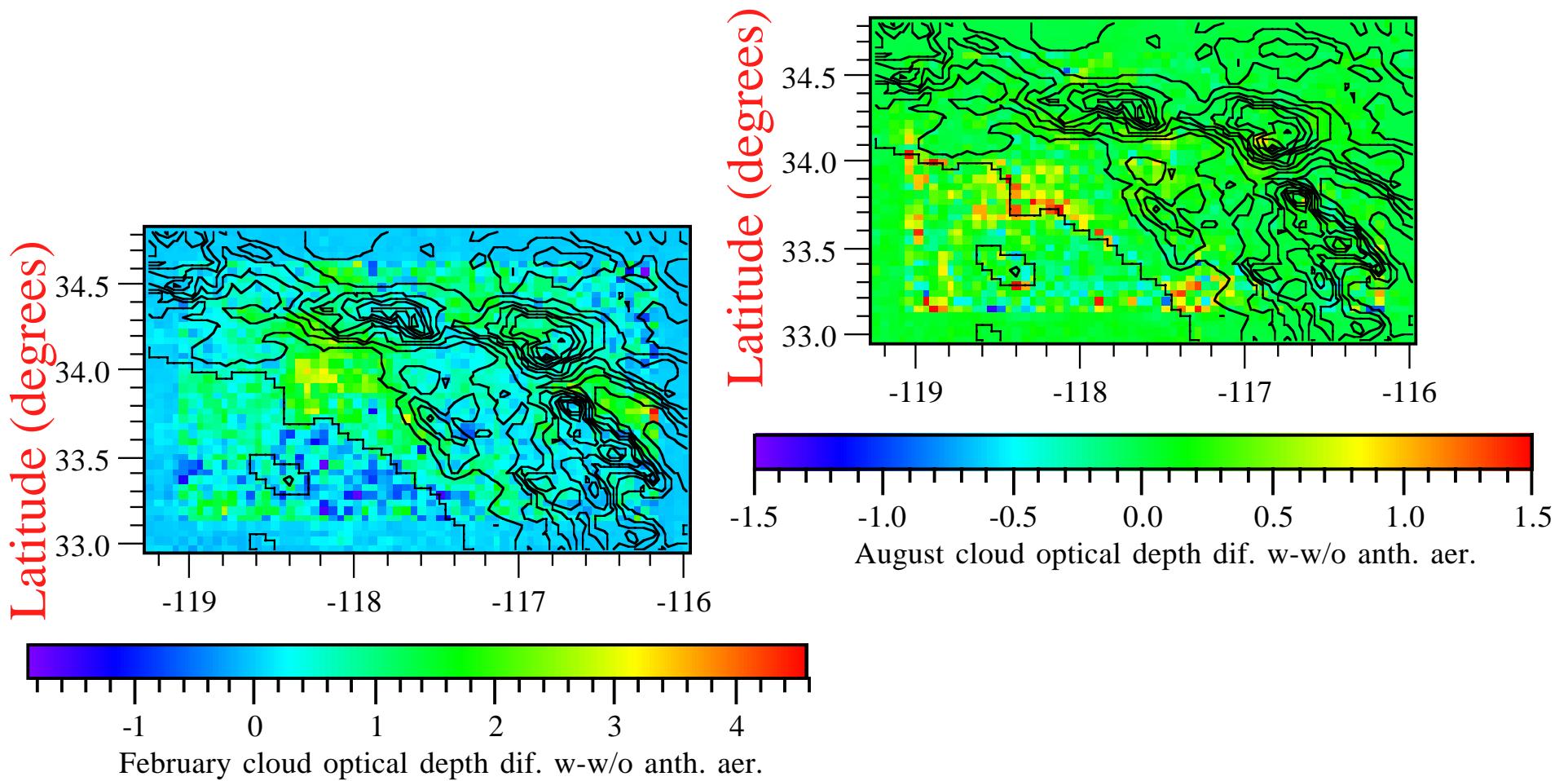
Paired-in-Time-and-Space Modeled (Red) v. Measured Wind Speed & Direction



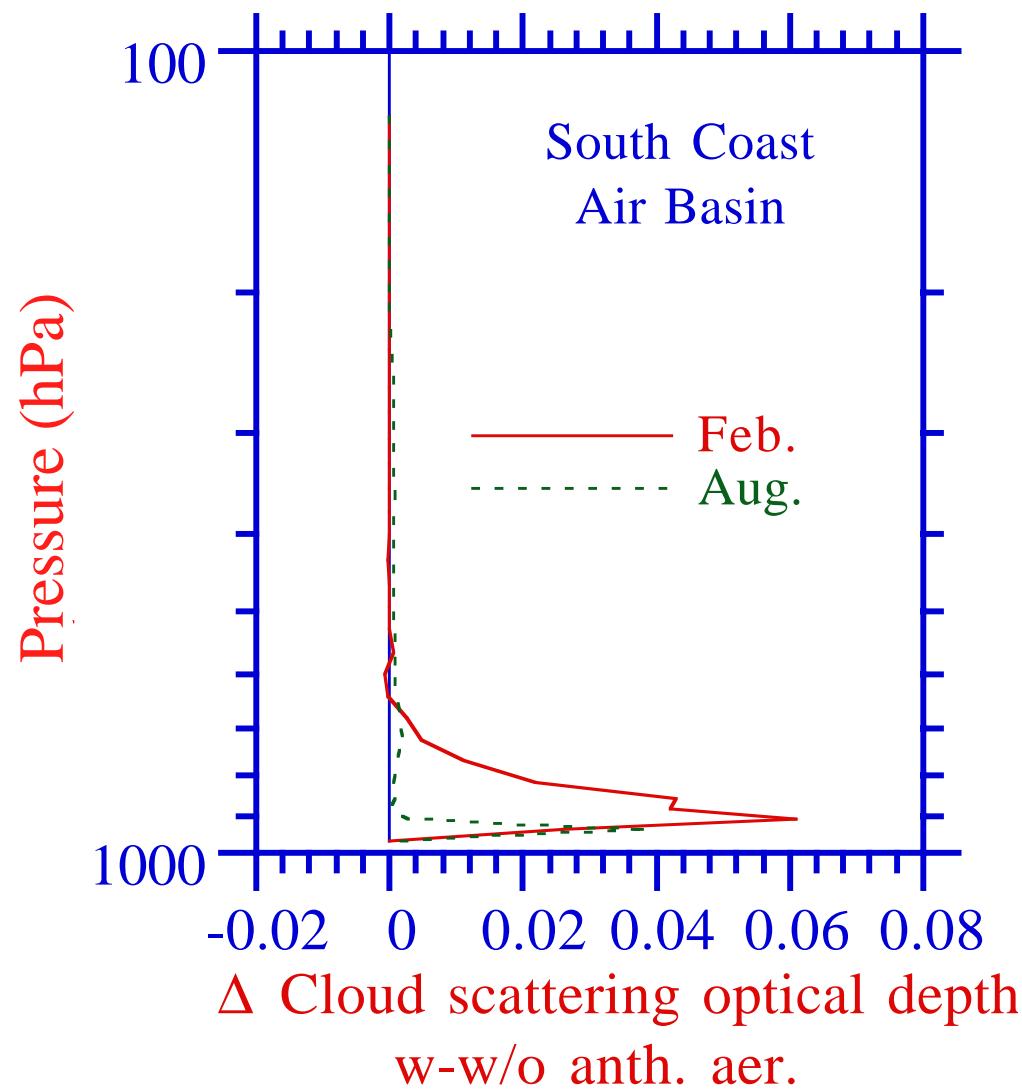
SCAB Aerosol Optical Depth Dif. w- w/o Anth.Aer.



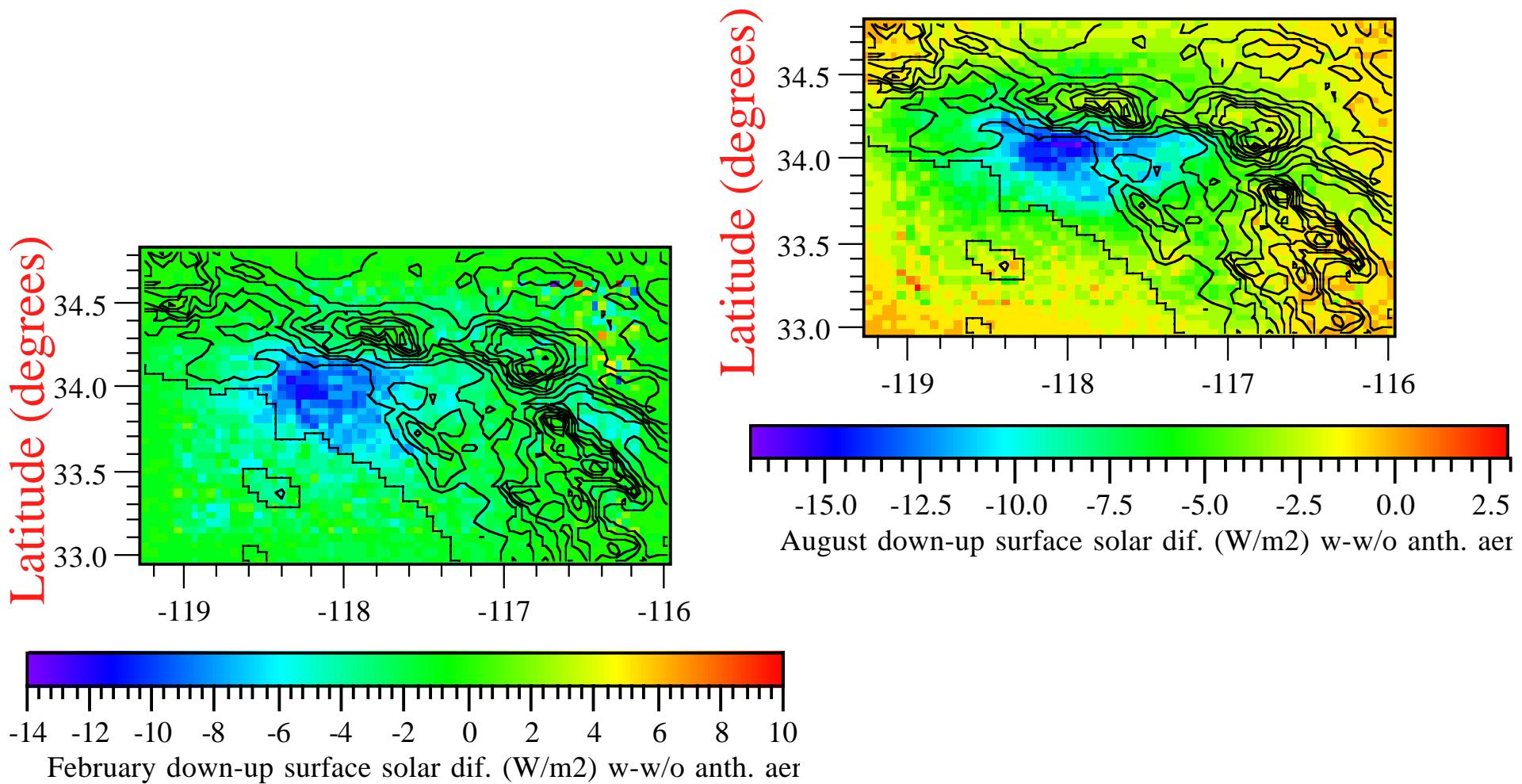
SCAB Cloud Optical Depth Dif. w-w/o Anth.Aer.



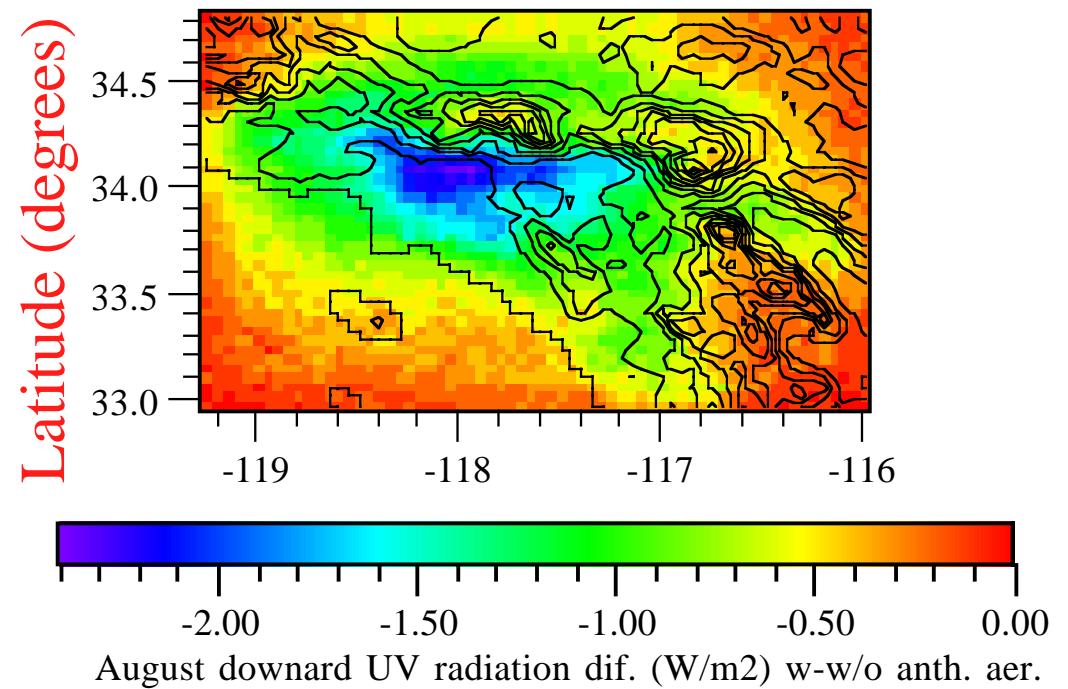
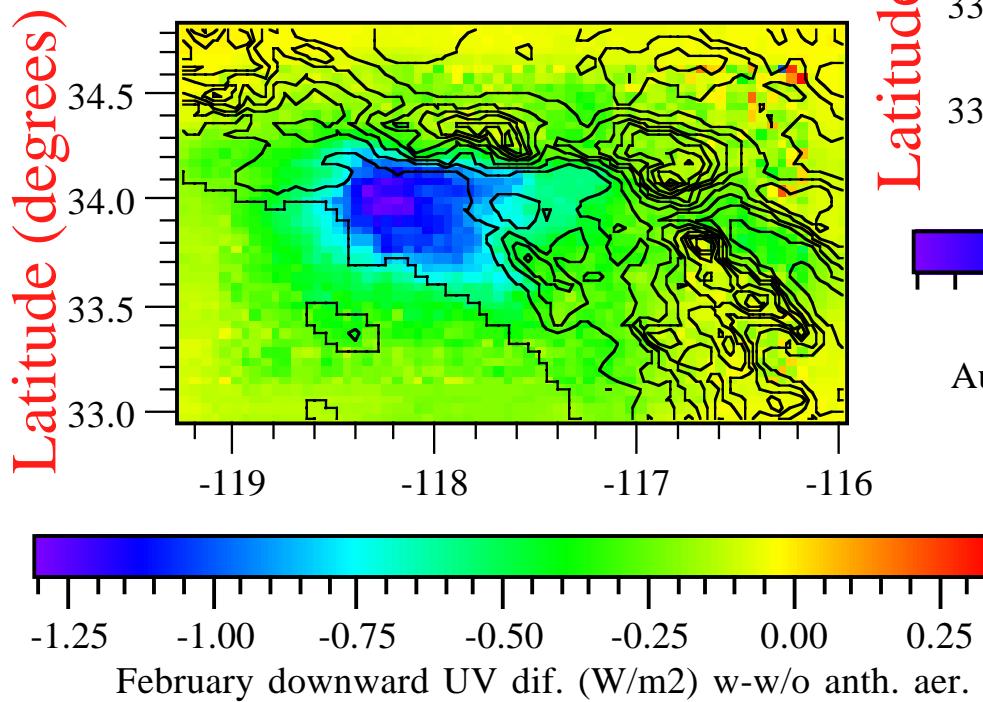
Cloud 550 nm Scattering Optical Depth Profile Dif.



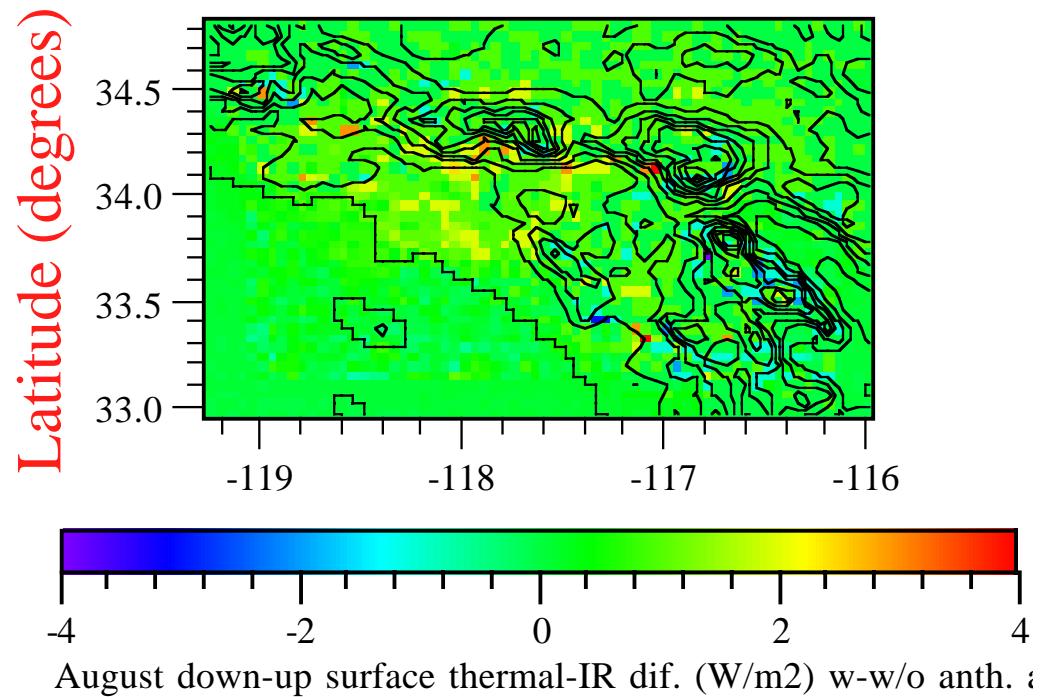
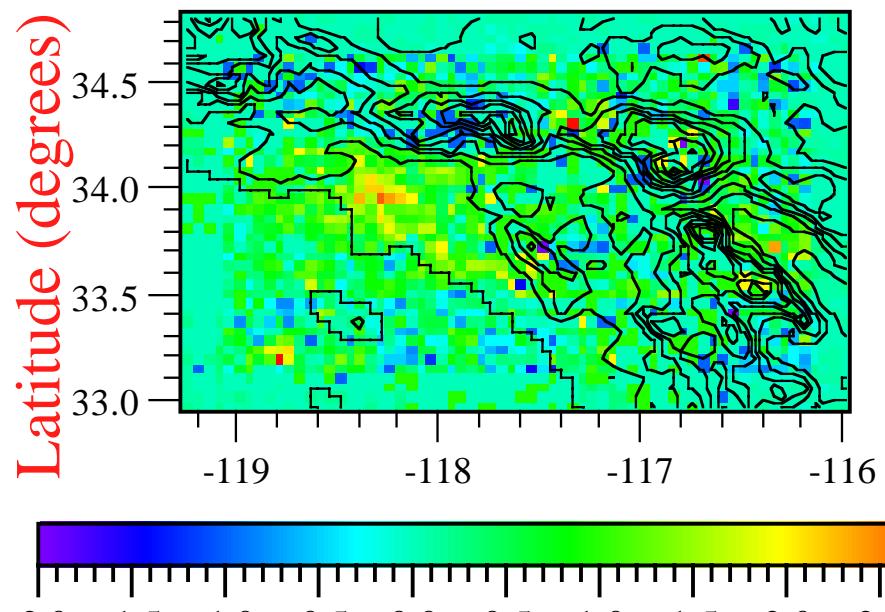
SCAB Down-Up Surface Solar Radiation Dif. w-w/o Anth.Aer.



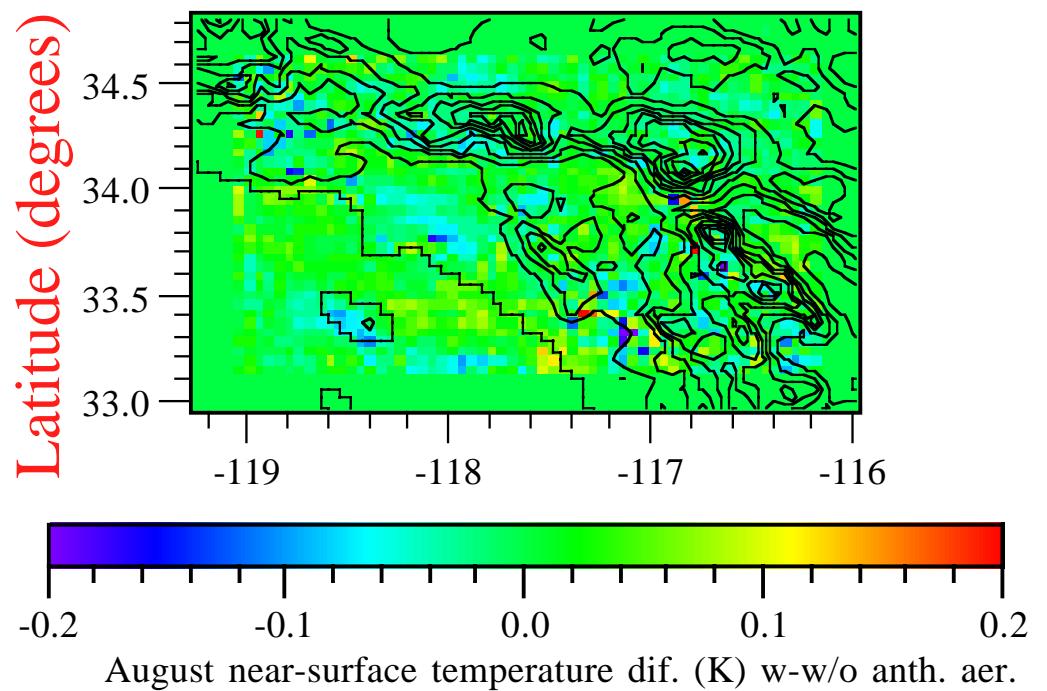
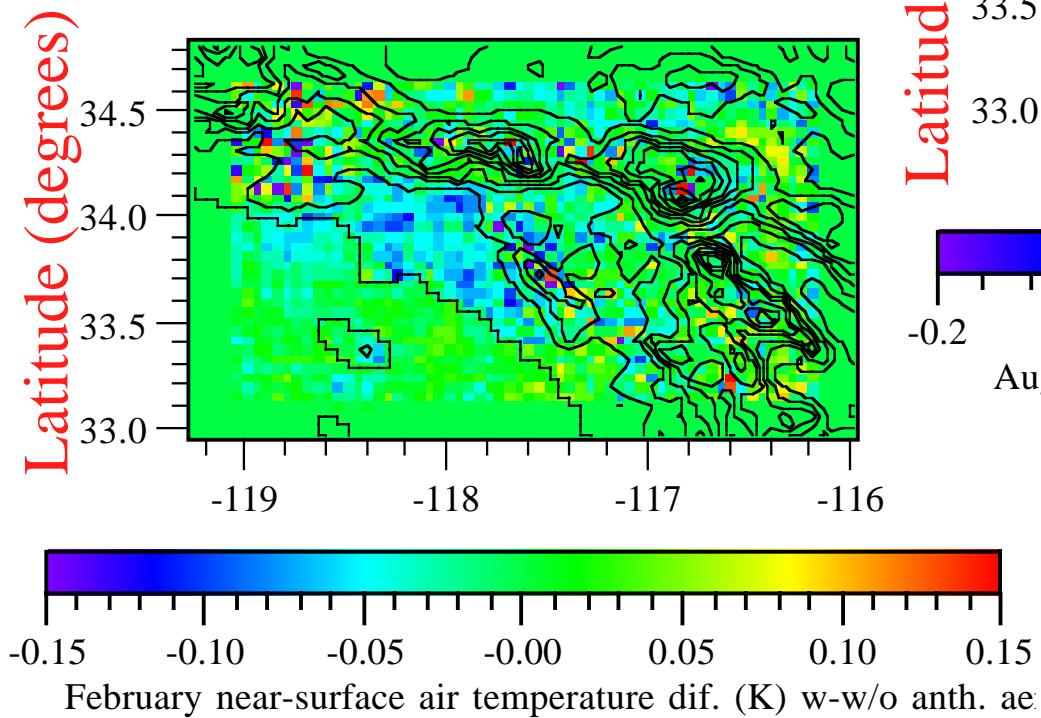
SCAB Downward UV Radiation Dif. w-w/o Anth.Aer.



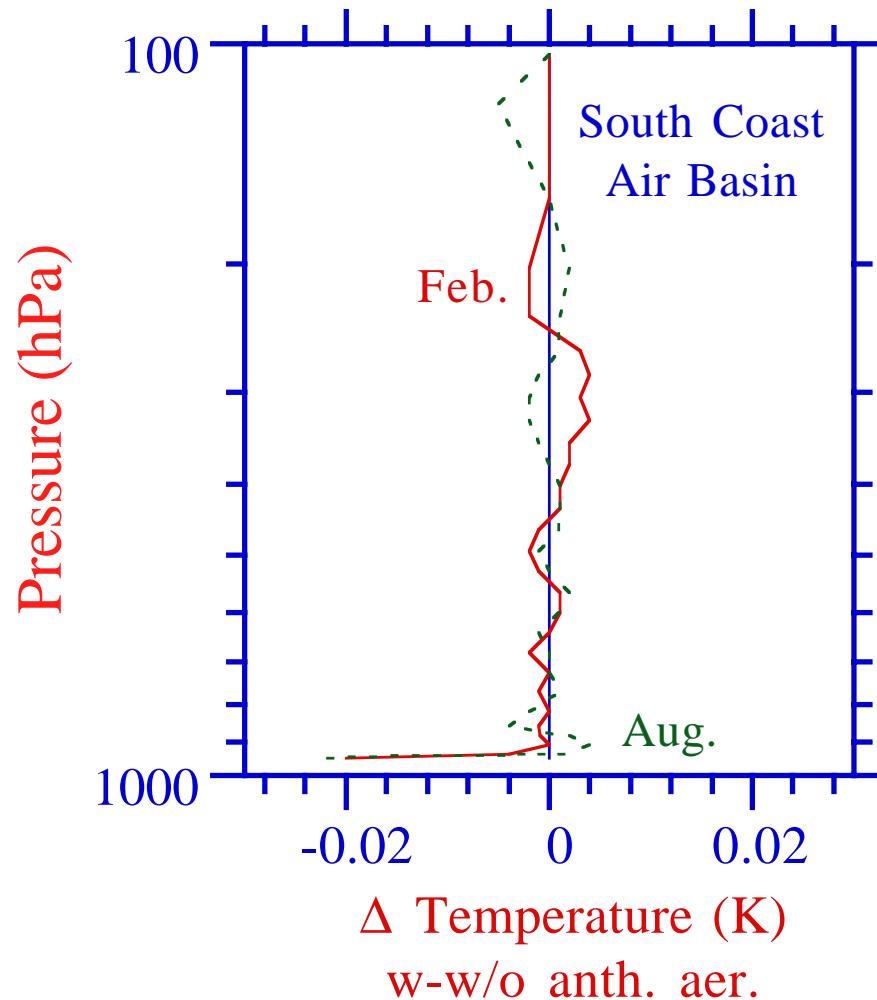
SCAB Down-Up Surface Thermal-IR Radiation Dif. w-w/o Anth.Aer.



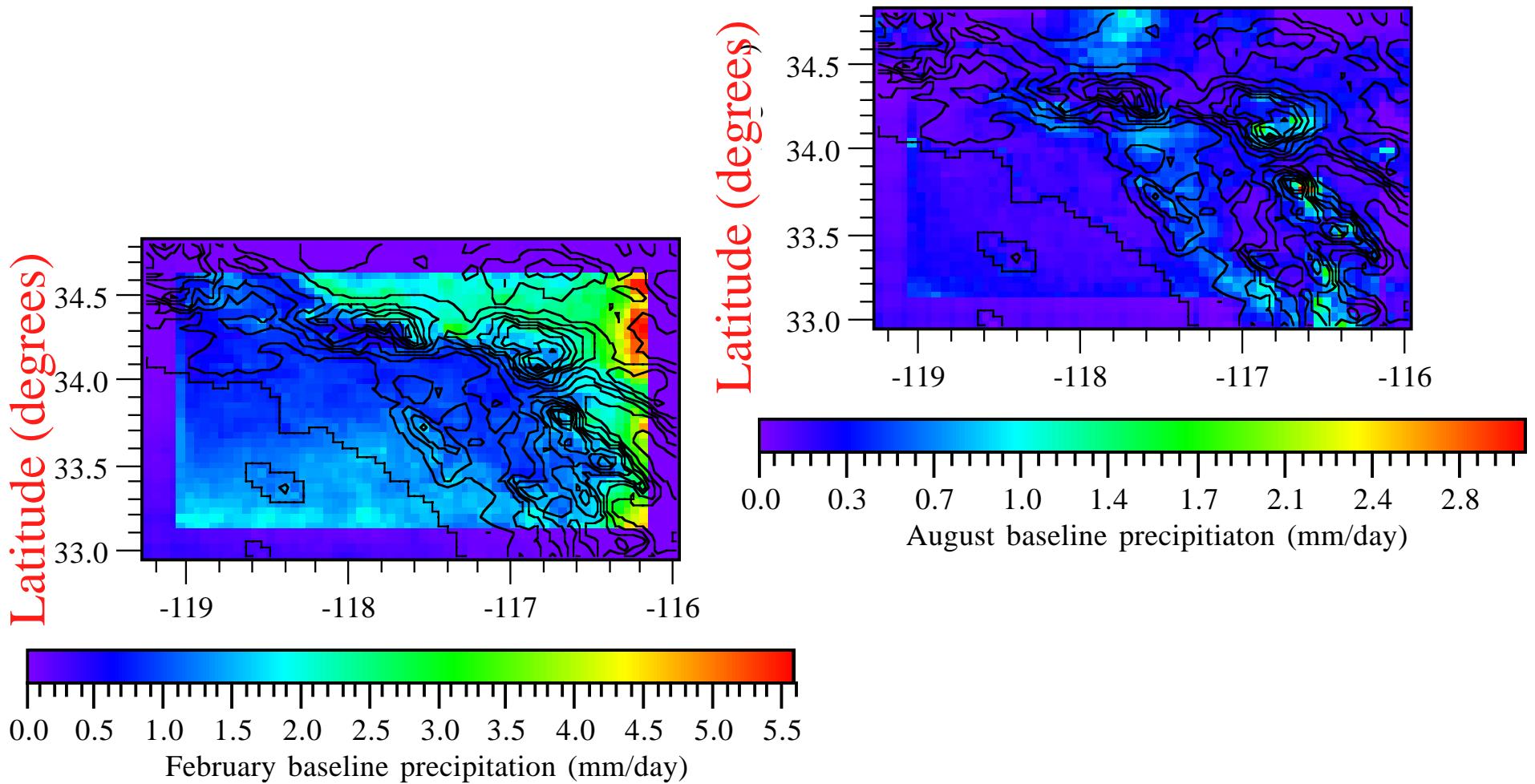
SCAB Near-Surface Temperature Dif. w-w/o Anth.Aer.



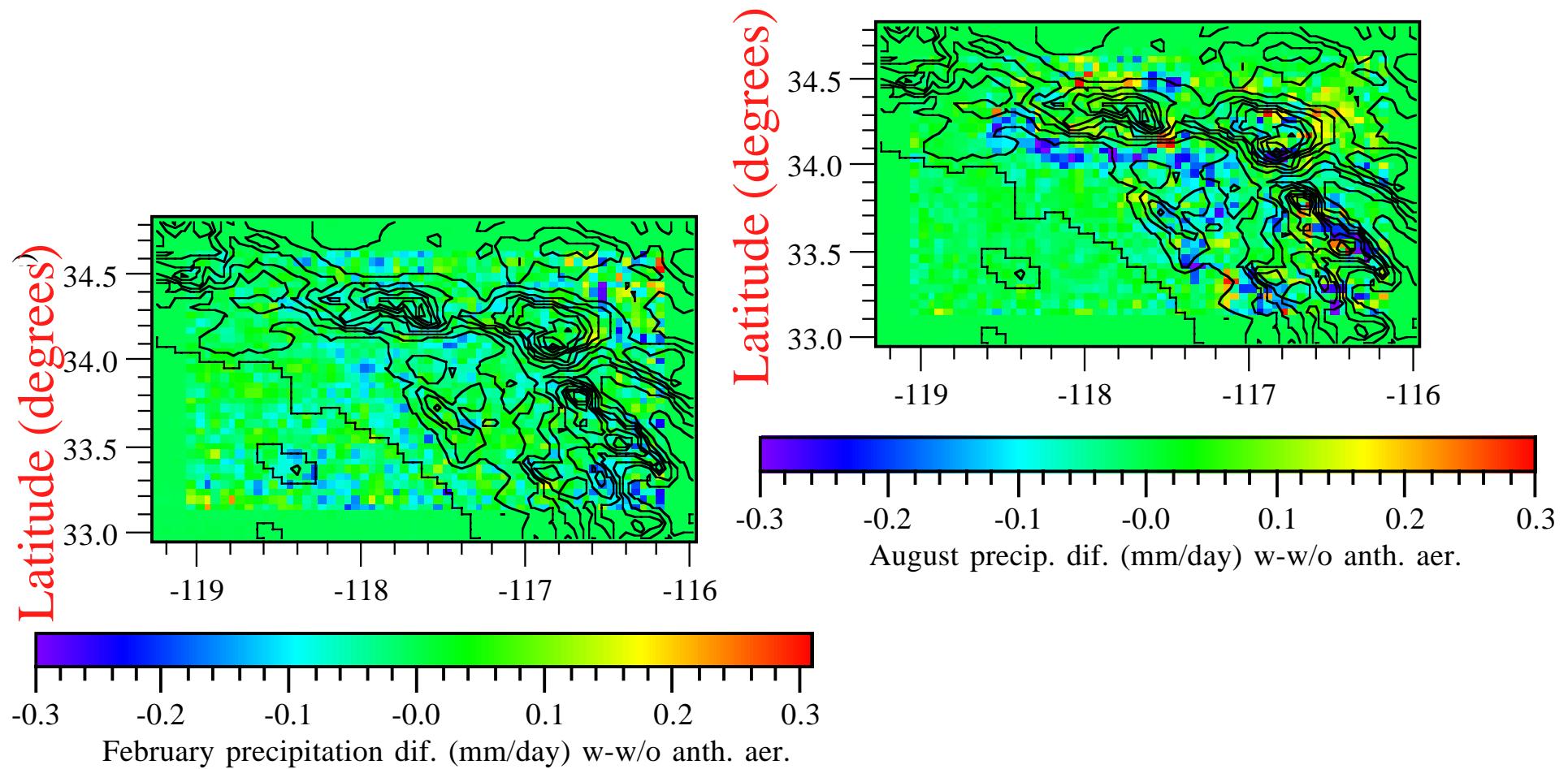
Temperature Profile Dif. Over SCAB



SCAB Baseline Precipitation (Including Fog Deposition)



SCAB Precipitation (Including Fog) Dif. w-w/o Anth.Aer.



Summary

Anthropogenic aerosols and gas precursors in California and the South Coast Air Basin were found to

- decrease rainfall in the Central Valley, South Coast, and mountains (e.g., Sierras, San Bernardino)
- increase the pollution content of rainfall
- increase cloud optical depth (up to 2x) and liquid water
- decrease ground temperatures in February/August
- decrease near-surface air temperatures in February
- slightly increase near-surface air temperatures in August
- slightly increase upper boundary-layer temperatures
- stabilize the boundary layer, increasing pollution
- decrease UV, solar radiation at surface
- increase thermal-IR radiation at surface

Summary

- On a global scale, ff+bf black carbon may cause a +0.25 to +0.3 K warming of global temperatures with a range of +0.15 to +0.5 K
- Warming due to soot absorption in snow and sea ice may be responsible for +0.06 K with a range of +0.03 to +0.11 K
- BC may reduce snow and sea ice albedo by about 0.4% globally and 1% in N. Hem. About 98% of BC removal from the atmosphere may be due to precipitation; the rest, to dry deposition.
- Maximum warming and cooling due to anthropogenic GHGs and aerosols appear to exceed those of GHGs alone. Aerosols act on top of GHGs to enhance extreme warm and cool climate conditions.

Acknowledgments

Guido Franco, Daniel Rosenfeld for comments

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California Energy Commission

Public Interest Energy Research (PIER) Program